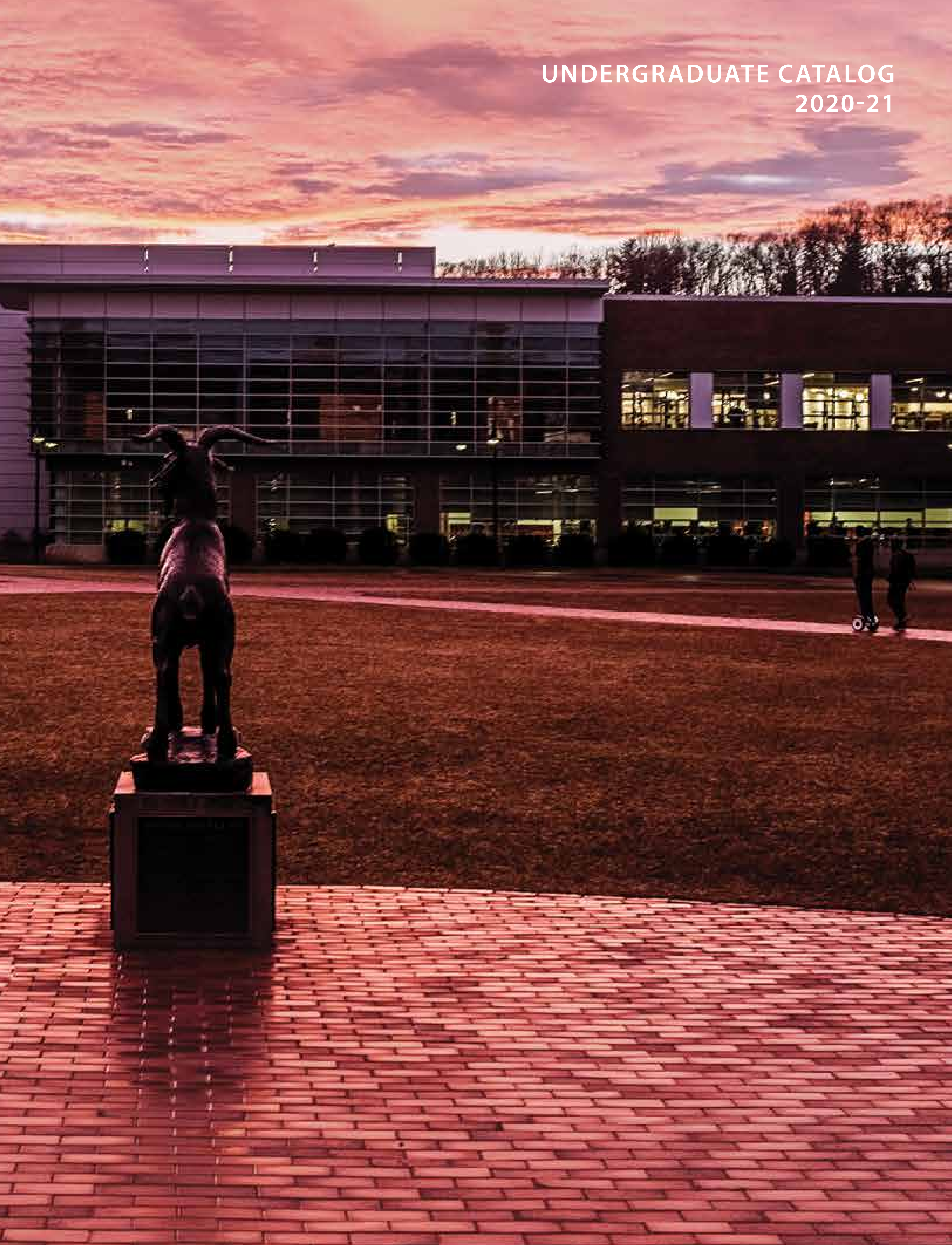
UNDERGRADUATE CATALOG
2020-21



CONTENTS

The Mission of WPI . . . 3
The Goal of WPI . . . 3
A Statement of Values for Undergraduate Education at WPI . . . 3
WPI Undergraduate Learning Outcomes . . . 4
WPI's Commitment to Pluralism . . . 4
The Two Towers Tradition: . . . 5
The Second Century . . . 5
The WPI Plan . . . 5

SECTION 1
THE WPI PLAN . . . 6

WPI Degree Requirements . . . 7
Major Areas of Study . . . 8
Professionally Accredited Programs . . . 9
Academic Advising . . . 10
Degree Options . . . 11
Concentrations . . . 11
Minors . . . 11
Double Majors . . . 12
Projects and Research . . . 14
The Major Qualifying Project . . . 17
MQP Learning Outcomes . . . 17
MQP Project Centers . . . 17
The Interactive Qualifying Project . . . 18
Global Projects Program . . . 19
Off-Campus Programs . . . 19
Individually Sponsored Residential Projects (ISRPs) . . . 21
Individually Sponsored On-Campus IQP Programs . . . 21
Humanities and Arts Requirement . . . 22
The Social Science Requirement . . . 27

SECTION 2
DEPARTMENT AND PROGRAM DESCRIPTIONS . . . 28

Department and Program Descriptions . . . 29
Aerospace Engineering . . . 29
  Minor in Aerospace Engineering . . . 32
Air Force Aerospace Studies . . . 32
Architectural Engineering . . . 33
  Minor in Architectural Engineering (AREN) . . . 34
Bioinformatics and Computational Biology . . . 36
  Minor in Bioinformatics and Computational Biology (BCB) . 37
Biology and Biotechnology . . . 37
  Minor in Biology . . . 38
Biomedical Engineering . . . 39
Business, Robert A. Foisie School of . . . 44
  Business (BU) . . . 44
  Management Engineering (MGE) . . . 47
  Management Information Systems (MIS) . . . 47
  Industrial Engineering . . . 48
  Minor in Business . . . 50
  Minor in Entrepreneurship . . . 50
  Minor in Industrial Engineering . . . 50
  Minor in Management Information Systems . . . 51
  Minor in Social Entrepreneurship . . . 51
Chemical Engineering . . . 52
Chemistry and Biochemistry . . . 54
  Minor in Biochemistry . . . 56
  Minor in Chemistry . . . 56
Civil and Environmental Engineering . . . 57
Computer Science . . . 60
  Minor in Computer Science . . . 63
Data Science . . . 65
  Minor in Data Science . . . 66
Electrical and Computer Engineering . . . 70
  Minor in Electrical and Computer Engineering . . . 73
Engineering Science Courses . . . 73
Environmental Engineering . . . 74
Fire Protection Engineering . . . 76
Humanities and Arts . . . 76
  Professional Writing . . . 79
  Humanities and Arts Minors . . . 80
  American Studies . . . 80
  Chinese Studies . . . 81
  Drama/Theatre . . . 82
  English . . . 82
  Language (German or Spanish) . . . 82
  History . . . 83
  Media Arts . . . 83
  Music . . . 83
  Philosophy and Religion . . . 84
  Writing and Rhetoric . . . 84
Interactive Media & Game Development . . . 84
  Interactive Media & Game Development (Bachelor of Arts) . 85
  Interactive Media & Game Development Technology (Bachelor of Science) . . . 86
  Minor in Interactive Media & Game Development . . . 87
Interdisciplinary and Global Studies . . . 87
Interdisciplinary Minors . . . 88
  Minor in Global Public Health . . . 88
  Minor in Nanoscience . . . 89
  Minor in Sustainability Engineering . . . 89
International Development, Environment, and Sustainability (IDEaS) (Bachelor of Arts Degree) . . . 90
  Major in Environmental and Sustainability Studies . . . 91
  Minor in Environmental and Sustainability Studies . . . 91
  Minor in Science and Engineering for Development (DEV) . . 92
International and Global Studies . . . 92
  Minor in International and Global Studies . . . 92
Liberal Arts and Engineering (Bachelor of Arts Degree) . . . 95
Mathematical Sciences . . . 97
  Minor in Statistics . . . 101
  Minor in Mathematics . . . 102
Mechanical Engineering . . . 102
  Minor in Mechanical Engineering . . . 106
  Minor in Manufacturing Engineering . . . 106
Materials Engineering . . . 107
  Minor in Materials . . . 107
Military Science . . . 108
Physical Education, Recreation, and Athletics . . . 109
Physics . . . 110
  Minor in Physics . . . 113
  Minor in Astrophysics . . . 114

Pre-Professional Programs 114
Five-Year Dual Bachelor/M.S. in Management (MSMG) . . . 114
Pre-Health Programs 115
Pre-Law Programs 115
Teacher Preparation Program 115
Robotics Engineering 116
Minor in Robotics Engineering 117
Social Science and Policy Studies 117
Economic Science Program 118
Psychological Science Program 119
Society, Technology, and Policy Program 120
Minor in Law and Technology 121
Minors in Social Science 121

SECTION 3
COURSE DESCRIPTIONS 123

Courses Qualifying for Engineering Distribution Areas 124
Course Descriptions 124
Aerospace Engineering 125
Air Force Aerospace Studies 126
Architectural Engineering 128
Basic Sciences 129
Bioinformatics and Computational Biology 129
Biology and Biotechnology 130
Biomedical Engineering 135
Business, Robert A. Foisie School of 138
Chemical Engineering 142
Chemistry and Biochemistry 144
Civil and Environmental Engineering 148
Computer Science 150
Data Science 154
Electrical and Computer Engineering 155
Engineering Science Interdisciplinary 158
Fire Protection Engineering 160
Humanities and Arts 161
Independent Study 179
Interactive Media & Game Development 179
Interdisciplinary 182
Mathematical Sciences 184
Mechanical Engineering 189
Military Science 192
Physical Education 194
Physics 195
Robotics Engineering 197
Social Science and Policy Studies 198

SECTION 4
UNIVERSITY POLICIES AND PROCEDURES 207

University Policies and Procedures 208
Grades 208
Grade Appeal and Grade Change Policy 209
Transfer Credit 211
Graduation with Honors 211
Commencement 212
Early Completion 212
Designation of Major Area of Study 212
Double Major 212
Designation of Class Year 212
Academic Honesty Policy 212
Guidelines for the Determination of Satisfactory Academic Progress, Academic Warning, Academic Probation and Academic Suspension 214
Administrative Obligations and Holds 215
Directory Information and Release of Information 215
Office of the Registrar 216
Part-Time Degree Students 219
Non-Degree Students 219

SECTION 5
RESOURCES AND SPECIAL PROGRAMS 221

Resources and Special Programs 222
The Gateway Park 222
Special Programs for First Year Students 222
Graduate Courses 222
Combined Bachelor/Master's Program 222
Information Technology Services 223
Music and Theatre Facilities 224
George C. Gordon Library 225
Student Services 226
Student Exchanges 227
Language Requirements 227
HECCMA Course Cross-Registration 228
Cooperative Education 228
Summer Session (Term E) 230
Awards and Prizes 231
Societies, Registration and Licensing 234

SECTION 6
CAREER DEVELOPMENT AND GRADUATE SCHOOL . . 235

Career Development and Graduate School Advising 236
Career Development Center 236
Graduate Study at WPI 237

SECTION 7
ADMISSION, EXPENSES, FINANCIAL AID AND HOUSING 241

Admission to WPI 242
Expenses 245
Financial Aid 247
Housing 251

SECTION 8
TRUSTEES ADMINISTRATION AND FACULTY 253

Trustees, Administration and Faculty 254
Trustees 254
Administration 256
Faculty 257
Index 280
Policies & Practices 284
Currency of Information 284
Accreditation 285
Directions 285
Campus Map 286

THE MISSION OF WPI

WPI educates talented men and women in engineering, science, management, and humanities in preparation for careers of professional practice, civic contribution, and leadership, facilitated by active lifelong learning. This educational process is true to the founders' directive to create, to discover, and to convey knowledge at the frontiers of academic inquiry for the betterment of society. Knowledge is created and discovered in the scholarly activities of faculty and students ranging across educational methodology, professional practice, and basic research. Knowledge is conveyed through scholarly publication and instruction.

Adopted by the Board of Trustees, May 22, 1987

THE GOAL OF WPI

WPI was founded in 1865 to create and convey the latest science and engineering knowledge in ways that would be most useful to the society from which its students came. Since that time, the disciplines of human inquiry have expanded extraordinarily, as have WPI's constituencies. The WPI curriculum, accordingly, has been reshaped numerous times, but it has remained true to its original mission of fusing academic inquiry with social needs, of blending abstraction with immediacy, of linking new knowledge to applications.

The goals of the undergraduate program are to lead students to develop an excellent grasp of fundamental concepts in their principal areas of study; to lay a foundation for life-long renewal of knowledge; to gain a mature understanding of themselves; and, most importantly, to form a deep appreciation of the interrelationships among basic knowledge, technological advance, and human need. These principles are today manifest in the *WPI Plan*, a unique, project-oriented program which emphasizes intensive learning experiences and direct application of knowledge. WPI remains committed to continued educational improvement and innovation.

The goals of WPI's programs of graduate instruction and research are to create and convey knowledge at the frontiers of academic inquiry. These endeavors are founded on the principle that vigorously pursued and rigorously assessed scholarship is the lifeblood of the institution. High quality graduate instruction conveys the arts of scholarship to new generations, and it assists working professionals in maintaining currency in a world where knowledge becomes obsolete with ever-increasing rapidity.

A WPI education encompasses continuous striving for excellence coupled with an examination of the contexts of learning so that knowledge is won not only for its own sake but also for the sake of the human community of which the people of WPI are part.

Endorsed by the WPI Faculty on March 5, 1987, and by the Board of Trustees on October 16, 1987.

A STATEMENT OF VALUES FOR UNDERGRADUATE EDUCATION AT WPI

1. WPI's programs shall emphasize fundamental concepts, knowledge, and skill, and ensure that students are able to apply them within the context of their major disciplines.
2. WPI's programs shall emphasize the development of students as effective thinkers and communicators, able to use evidence to present their ideas with logic, clarity, and persuasion.
3. Programmatic breadth in general, and balance between technical and humanistic components in particular, are the hallmarks of a WPI undergraduate education. In addition to educating students in their major discipline, WPI's programs shall provide students with a broad preparation for fulfilling lives as responsible professionals and informed citizens.
4. Grounded in project and course experiences, a WPI education shall provide a firm foundation for life-long learning in a variety of fields. WPI programs shall emphasize inquiry-based learning and open-ended problem solving. Students shall bear a considerable responsibility for learning outside of the classroom.
5. WPI's programs shall be sufficiently flexible so as to allow students significant choice in and responsibility for planning their courses of study. Faculty, via the central teaching tasks of project and academic advising, shall ensure that student learning experiences encourage critical reflection, decision making, and personal growth.
6. WPI's programs shall emphasize the scientific, technical, societal, and humanistic contexts in which knowledge is applied and constructed. Education activities shall challenge students to make connections between disciplines, to consider multiple viewpoints, and to appreciate the consequences of their actions. The curriculum shall prominently feature integrative and interdisciplinary activities.
7. WPI's learning environment and educational activities shall balance personal responsibility and individual accountability with cooperation, collaboration and mutual respect. Members of the community shall be encouraged to value academic integrity, and to become conscious of the value that such integrity confers to themselves and to the community.
8. WPI shall be committed to assessment and improvement of student learning.

WPI UNDERGRADUATE LEARNING OUTCOMES

Graduates of WPI will:

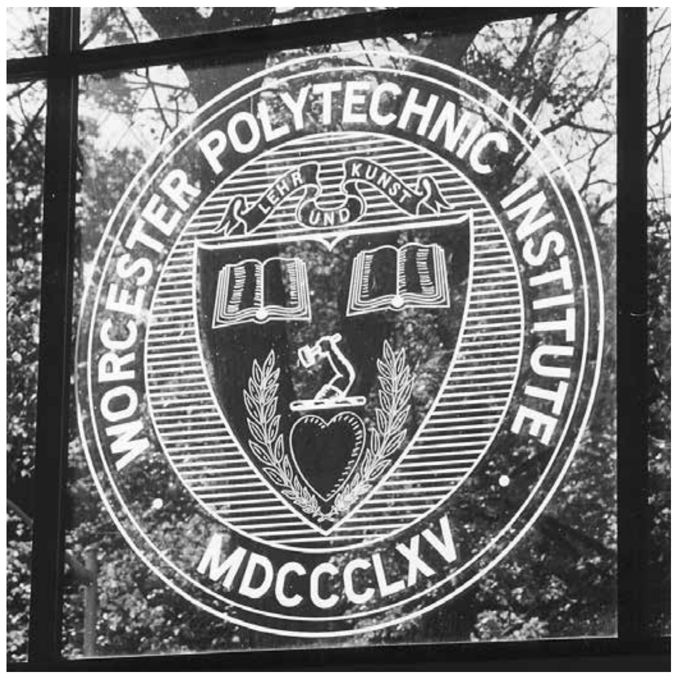
1. have a base of knowledge in mathematics, science, and humanistic studies.
2. have mastered fundamental concepts and methods in their principal areas of study.
3. understand and employ current technological tools.
4. be effective in oral, written and visual communication.
5. function effectively both individually and on teams.
6. be able to identify, analyze, and solve problems creatively through sustained critical investigation.
7. be able to make connections between disciplines and to integrate information from multiple sources.
8. demonstrate global and intercultural competency by developing the capacity to identify, explain, and critically analyze the forces (such as cultural, historical, political, economic) that shape the self and others as they engage with local and global communities.
9. be aware of personal, societal, and professional ethical standards.
10. have the skills, diligence, and commitment to excellence needed to engage in lifelong learning.

Approved by the WPI Faculty on May 3, 2019.

WPI'S COMMITMENT TO PLURALISM

Pluralism, as a social condition, means that several distinct ethnic, religious, and racial communities live side by side, have equitable access to resources, are willing to affirm each other's dignity, are ready to benefit from each other's experiences, and are quick to acknowledge each other's contributions to the common welfare. Recognizing the importance of pluralism to creativity, innovation, and excellence, WPI is dedicated to creating an atmosphere that encourages diversity in all aspects of campus life–from academics, to residence hall living, to social interactions among students, faculty, and staff. The Institute recognizes the special obligation of promoting a multicultural community based on mutual respect and tolerance. This commitment is part of WPI's institutional plan for encouraging pluralism and increasing diversity, a plan that proclaims the importance of having students understand and appreciate other cultures, and prepares them fully to pursue rewarding careers in an increasingly global economy.

Concepts endorsed by the WPI Faculty on April 21, 1994.



THE TWO TOWERS TRADITION: THE SECOND CENTURY

WPI, the nation's third oldest private technological university, was established in 1865 by the New England industrialists John Boynton, Ichabod Washburn, and their associates. Boynton and Washburn endowed the first two buildings on campus, as academic classrooms and practical shops. Boynton Hall and the Washburn Shops — renovated today into state-of-the-art facilities — still preserve their distinctive original towers. These "Two Towers" represent WPI's continued commitment to academic excellence through real-life project experience that synthesizes classroom learning.

The "Two Towers" tradition of academic achievement and practical application is reflected in WPI's motto, "Lehr und Kunst" or "Theory and Practice."

WPI has awarded graduate degrees since 1898, adding new programs regularly in response to the developing needs of the professional world. WPI is among the top 50 science colleges in the nation in terms of the percentage of undergraduates who receive doctorates. Presently, WPI offers the master's degree in 31 disciplines and the doctorate in 15.

The current student body of over 4,000 men and women includes about 1,100 full- and part-time graduate students. Currently, students attend WPI from almost every state and over 70 foreign nations.

THE WPI PLAN

In 1970 WPI adopted a revolutionary new undergraduate program known as the *WPI Plan*. The Plan replaced the traditional rigidly-prescribed curriculum — typical of conventional engineering education — with a flexible, exciting, and academically challenging program aimed at helping students to learn *how to learn*.

The Plan continues the "Two Tower" tradition by synthesizing classroom experience in projects that solve real-world problems. The WPI project program prepares graduates for their future professional lives by helping them learn how to identify, investigate and report on open-ended problems. Alumni indicate that project experiences also prepare them uniquely well for managing team efforts, and for communicating both in oral and written forms according to professional standards.

All WPI students complete two major projects in addition to requirements in general education and in their major fields. The Major Qualifying Project (or MQP) challenges students to solve research and design problems typical of those encountered in their professional discipline. The Interactive Qualifying Project (or IQP) presents an issue at the intersection of science, technology, and culture, and emphasizes the need to learn about how technology affects societal values and structures. Students also achieve intellectual breadth through degree requirements in the social sciences and humanities and arts. In addition, students achieve some depth within the Humanities and Arts by completing an Inquiry Seminar or Practicum on a theme emerging from a self-selected series of courses. Taken together, these activities emphasize that professionals must learn not only to create technology, but also to assess and manage the social and human consequences of that technology.

THE WPI PLAN

SECTION 1

WPI Degree Requirements 7
Major Areas of Study 8
Professionally Accredited Programs 9
Academic Advising 10
Degree Options 11
Concentrations 11
Minors 11
Double Majors 12
Projects and Research 14
The Major Qualifying Project 17
MQP Learning Outcomes 17
MQP Project Centers 17
The Interactive Qualifying Project 18
Global Projects Program 19
Off-Campus Programs 19
Individually Sponsored Residential Projects (ISRPs) 21
Individually Sponsored On-Campus IQP Programs 21
Humanities and Arts Requirement 22
The Social Science Requirement 27

WPI DEGREE REQUIREMENTS (effective for students matriculating after August 1, 2011)

WPI's academic requirements are specifically designed to develop an overall educational experience which meets the goals of the college. Each requirement plays a supporting role as follows:

- To provide intellectual breadth and a better understanding of themselves and the diversity and creativity of human experience, every WPI student must complete a **Humanities and Arts Requirement**;
- To provide an understanding of the priorities of other sectors of society, develop the ability to communicate effectively with disparate groups, organize and derive solutions to complex problems, and gain an awareness of the interrelationships between technology and people, every WPI student must complete an **Interactive Qualifying Project (IQP)**;
- To provide a capstone experience in the professional discipline, to develop creativity, instill self-confidence and enhance the ability to communicate ideas and synthesize fundamental concepts, every student must complete a **Major Qualifying Project (MQP)**;
- To provide for learning through an academic program with fabric and course balance while encouraging individual student choices within that framework, every student must fulfill **Distribution Requirements**.

WPI TERMS AND CREDIT UNITS

The Bachelor degree from WPI normally is based upon a residency at WPI of 16 terms. WPI operates on a system with four seven-week *terms*, two in the autumn semester (Terms A and B) and two in the spring semester (Terms C and D). A summer session, Term E, is also available. The normal academic load for each term is defined as *one unit* of work, usually divided among three courses or projects. Thus, the usual credit unit for courses or independent study/projects is 1/3 unit. *Qualifying Projects*, defined on pages 14-16, require one full unit of activity which may be concentrated into a single term (especially if conducted off-campus) or spread throughout an academic year. The degree will be awarded upon completion of the following:

DEGREE REQUIREMENTS

1. **The Humanities and Arts Requirement** (See page 22)
   Qualification by overall evaluation of two units of work in the humanities and arts.
   To provide intellectual breadth and a better understanding of themselves and the diversity and creativity of human experience, every WPI student must complete a **Humanities and Arts Requirement**.
2. **The Mathematics and Science Requirement** (See distribution requirements for individual programs, starting on page 28)
   The Mathematics and Science Requirement defines a minimum standard of scientific, technological, engineering, and mathematical literacy for graduates of WPI, regardless of major field. Most degree programs will provide a substantial level of preparation in most of these areas, far beyond this standard. Students will satisfy this requirement by satisfying the program requirements of their individual major programs.
   The goals of the Mathematics and Science Requirement at WPI are that students will be able, in their careers and daily lives, to: 1) explain and apply key concepts and principles of scientific disciplines and use an understanding of scientific methods to make critical judgments, 2) apply mathematical methods to understand the solution of real-world problems, 3) productively and appropriately use computers and other technology, 4) use methods from the quantitative, natural or engineering sciences to systematically identify, formulate, and solve problems.
   The specific requirement is two units of work in science, engineering, mathematical science or computer science. Two-thirds units of work must be in Quantitative Science (courses with prefixes CS or MA count by default); two-thirds units of work must be in Natural or Engineering Science (courses with prefixes BB, BME, CHE, CE,CH, ECE, ES, GE, ME, PH or RBE count by default); the final two-thirds unit may be from any of the Quantitative, Natural or Engineering Sciences. Each major program may set more restrictive requirements as the program sees fit. Programs may also propose other work to fulfill any portion the two-unit Requirement; such alternatives must be approved by the Committee on Academic Policy and the Dean of Undergraduate Studies.
3. **The Interactive Qualifying Project** (See page 18)
   Successful completion of a qualifying project relating science and/or technology to society (the Interactive Qualifying Project, or IQP) representing at least one unit of credit in project or independent study work. The format of the documentation is to be in accordance with current WPI policy on such documentation.
4. **The Major Qualifying Project** (See page 17)
   Successful completion of a qualifying project in the major area of study (the Major Qualifying Project, or MQP) representing at least one unit of credit in project or independent study work. The format of the documentation is to be in accordance with current WPI policy on such documentation.
5. **Distribution Requirements** (See program description for specified departments – page 28)
   Satisfaction of published academic activity distribution requirements in or relating to the major area of study. These requirements typically total no more than ten units (including the MQP and two units to fulfill the Mathematics and Science Requirement) and are specified by general topical subject area, not by specific courses. Completion of distribution requirements will be certified by the appropriate Program Review Committee (PRC), upon recommendation by the student's academic advisor. For students desiring designation of a major area for which a determination regarding distribution requirements has not previously been made and published, a faculty committee will be appointed by the department head or IGSD dean to review and approve the student's program of study.

6. **Social Sciences** (See page 27)
   Completion of 2/3 unit of work in the social sciences, exclusive of qualifying project.
7. **Residency Requirement**
   A minimum of eight units *must* be completed satisfactorily in residence at WPI. (It is anticipated the normal residence at WPI will be 16 terms.)
8. **Minimum Academic Credit**
   The minimum academic credit required for the Bachelor degree is 15 units. Credit accumulated beyond the published distribution requirements shall be accomplished by the addition of "free elective" work.
9. **Physical Education** (See page 109)
   Qualification in physical education shall be established by completing 1/3 unit of course work (four PE classes) or its equivalent. Such an equivalent, for example, may be participation in club or varsity sports.

MAJOR AREAS OF STUDY

Guidelines for the construction of the most common major programs are given alphabetically by area in the "Department and Program Descriptions" section beginning on page 28. The exact program of study for any student, however, is developed by the student with the aid of an advisor.

All of the majors below, with the exception of Environmental and Sustainability Studies, Interactive Media and Game Development, and Liberal Arts and Engineering, are awarded with the B.S. degree. Some programs are listed that are developed through the departments indicated in parentheses. In the past, WPI has graduated students in the following fields, but this list should not be interpreted as necessarily putting any restriction on a student's "major:"

- Actuarial Mathematics (MAC)
- Aerospace Engineering (ME)(accredited by ABET)
- Applied Physics (PHA)
- Architectural Engineering (AREN)
- Biochemistry (CBC)(certified by the American Chemical Society)
- Bioinformatics and Computational Biology (BCB)
- Biology/Biotechnology (BB)
- Biomedical Engineering (BME)(accredited by ABET)
  - Specializations in:
    - Biomaterials and Tissue Engineering
    - Biomechanics
    - Biomedical Instrumentation, Biosignals, and Image Processing
- Business (BU) (accredited by AACSB)
  - Concentrations in:
    - Business Analytics
    - Financial Technology
    - Innovation for Social Change
    - General Business
    - Custom concentration
- Chemical Engineering (CHE)(accredited by ABET)
  - Concentrations in:
    - Biochemical
    - Biomedical
    - Environmental
    - Materials
- Chemistry (CBC)(certified by the American Chemical Society)
  - Concentration in:
    - Medicinal Chemistry
- Civil Engineering (CEE)(accredited by ABET)
  - Subareas in:
    - Structural and Geotechnical Engineering
    - Environmental Engineering
    - Transportation Engineering
    - Urban and Environmental Planning
    - Construction Engineering and Project Management
  - Concentration in:
    - Environmental
- Computer Science (CS)
- Data Science (DS)
- Economic Science (SSPS)
  - Concentrations in:
    - Sustainable Economic Development
    - Computational Economics
- Electrical and Computer Engineering (ECE)(accredited by ABET)
  - Subdisciplines in:
    - Robotics
    - Power Systems Engineering
    - RF Circuits and Microwaves
    - Communications and Signal Analysis
    - Biomedical Engineering
    - Analog Microelectronics
    - Computer Engineering
- Environmental Engineering (CEE; CHE) (accredited by ABET)
- Environmental and Sustainability Studies (B.A. degree) (ID)
- Humanities and Arts (HU)
  - Concentrations in:
    - American Studies
    - Environmental Studies
    - Humanities Studies of Science and Technology
    - History
    - Literature
    - Music
    - Philosophy, Religion
    - Drama/Theatre
    - Writing and Rhetoric
    - Art History
    - German Studies
    - Hispanic Studies
    - Science and Technology

Industrial Engineering (BU) (accredited by ABET)
Interactive Media & Game Development (B.A. degree) (HU; CS)
Interactive Media & Game Development Technology (HU; CS)
Interdisciplinary (by arrangement)(IGSD)
International and Global Studies (HU)
Liberal Arts and Engineering (B.A. degree)(HU)
Management Engineering (BU)(accredited by AACSB)
- Concentrations in:
  - Biomedical Engineering
  - Chemistry
  - Civil Engineering
  - Electrical and Computer Engineering
  - Mechanical Engineering
  - Manufacturing Engineering
  - Operations Management
  - Custom concentration

Management Information Systems (BU)(accredited by AACSB)
Mathematical Sciences (MA)
- Subareas in:
  - Algebraic and Discrete Mathematics
  - Computational and Applied Analysis
  - Operations Research
  - Probability and Statistics

Mechanical Engineering (ME)(accredited by ABET)
- Concentrations in:
  - Biomechanical
  - Engineering Mechanics
  - Manufacturing
  - Materials Science and Engineering
  - Mechanical Design
  - Robotics
  - Thermal-Fluid Engineering

Physics (PH)
Professional Writing (HU)
Psychological Science (SSPS)
Robotics Engineering (CS; ECE; ME)(accredited by ABET)
Society, Technology and Policy (SSPS)

Programs for students interested in medicine, law or pre-college education can be readily developed from many of the above majors.

Interdisciplinary (individually-designed) majors (ID) may also be developed under the B.S. or B.A. degree; see Interdisciplinary Programs, page 87.

WPI undergraduate diplomas designate “Bachelor of Science” or “Bachelor of Arts” as appropriate. The transcript will list the student’s major. If a Minor or Concentration was completed, this will also be included on the transcript.

The number of majors associated with a single WPI Bachelor’s degree is **limited to two**.

PROFESSIONALLY ACCREDITED PROGRAMS

WPI is accredited as an institution by the **New England Commission of Higher Education.** In addition, the aerospace engineering, architectural engineering, biomedical engineering, chemical engineering, civil engineering, electrical and computer engineering, environmental engineering, industrial engineering, mechanical engineering, and robotics engineering programs are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org. The Chemistry and Biochemistry Department and its program are approved by the **American Chemical Society**. The bachelor’s and master’s degree programs offered by the Robert A. Foisie School of Business are accredited by **AACSB International — The Association to Advance Collegiate Schools of Business**.

WPI's advising program is based on a cooperative and understanding relationship between the students and advisors. Under the WPI Plan, ***students have the final responsibility*** for designing their own educational experience at WPI which includes ***understanding all their degree requirements and making sure all those requirements have been satisfied for graduation***. The role of the faculty advisor is to help his/her advisees design a program of study which reflects the students' interests and professional goals. While advisors are willing to suggest specific programs of study, they will not insist that students follow a particular path. Advisors also help students choose among academic alternatives, help them interpret catalog requirements and review degree audits and grade reports with them. Students are expected to understand these documents and their implications for academic progress and act accordingly. Therefore it is critical that students take the initiative to consult regularly with their academic advisors.

The Office of Academic Advising at WPI has three main areas of focus: 1) general academic advising; 2) academic resources; and 3) pre-health programs.

GENERAL ACADEMIC ADVISING

Students can come to the Office of Academic Advising to get general advising help in areas such as course selection, academic status concerns, major and advisor selection, and individualized academic coaching. The Office of Academic Advising oversees programming for the First Year, including the Insight Program and the Insight Wellness course.

The academic coaching program includes counseling from an Academic Advisor in areas such as learning styles, effective study strategies, problem solving and critical thinking skills, and time management. Students work on setting their academic goals, discovering their strengths and weaknesses, and designing learning and study strategies that work best for them.

ACADEMIC RESOURCES CENTER

The Academic Resources Center (ARC) at WPI is located in Daniels Hall, and houses the academic tutoring program and MASH (Math and Science Help). Peer tutors and academic coaches are students who have demonstrated a mastery of material, and have been trained in peer tutoring and communication.

The MASH program is an academic support program for students enrolled in math and science classes. Offered to all students in a supported course, MASH provides assistance in regularly scheduled weekly study sessions beginning the first week of every term.

MASH review sessions are offered for a limited number of courses which students and faculty have identified as challenging. Many of the courses are typical first year classes, allowing extra support for students transitioning to college-level work. Each session is guided by a MASH leader, an undergraduate student who has taken the course before and has excelled. He/she understands the course material and what the instructor expects. MASH leaders attend lectures so they are prepared for questions that might arise in a MASH session.

Through the MASH and tutoring programs students become actively involved with the content material in a supportive environment. Studies show that students who attend MASH or tutoring regularly earn higher grades than students electing not to participate. Even more importantly, they learn how to master new concepts, learn how to put ideas into perspective, develop a better way to study, and effectively manage their time.

PRE-HEALTH ADVISING

The Pre-Health Advisor works with students who are interested in pursuing careers in the health professions. Students may meet with the Pre-Health Advisor to a) explore various careers in healthcare and receive assistance in selecting the most suitable path for themselves; b) receive advice regarding pre-requisite courses and other preparation for various health professions programs (e.g. medicine, dentistry, veterinary medicine, optometry, physician assistant studies, physical therapy, among others; c) receive assistance throughout the professional school application process, including the arrangement of a committee recommendation letter; d) take advantage of academic coaching or receive general help. The Office of Academic Advising collaborates with the Career Development Center and other offices on campus to offer special programming for pre-health students. Students may make an appointment for any of these services by contacting the Office of Academic Advising at 508-831-5381.

OFFICE OF DISABILITY SERVICES

Academic accommodations are available for students with documented disabilities. Please see page 226 for more information.

CONCENTRATIONS

DEFINITION

A Concentration is an option associated with a major which provides recognition for focused and coordinated academic work either within the major or within an area of study closely related to the major.

RULES

1. All Concentrations require completion of two units of integrated academic study plus an MQP with a topic and content appropriate to the given Concentration.
2. Concentrations deemed to belong exclusively or primarily within the stated major must be accommodated within the distribution requirements of that major.
3. Concentrations deemed to have a substantial interdisciplinary nature can exceed the normal 10-unit allotment of the major by as much as 1 unit, provided that the additional requirements do not include or permit academic work designated by the major prefix or coursework normally taken to satisfy the major's portion of the distribution requirements. Furthermore, Concentrations of an interdisciplinary nature are permitted to use up to 1 unit of the academic program beyond the distribution requirements of the major, including the IQP, Social Science requirement, and Free Electives, as deemed appropriate.
4. The requirements of the Concentration must be designed to offer choices for the student within the major area and, if relevant, outside the distribution requirements of the major; however, the Concentration requirements must not preclude meeting the normal distribution requirements for the major.
5. Rules and guidelines for each Concentration will be formulated by the faculty associated with the governing major, and must be reviewed by the Committee on Academic Operations (CAO) and subsequently approved by the Faculty. CAO is empowered to rule on whether a proposed Concentration is disciplinary or interdisciplinary.
6. An individual program of study leading to a major with a Concentration will be planned by a student in consultation with his/her academic advisor. The student's intention to pursue a Concentration will be declared by application to the appropriate Program Review Committee in accordance with that Committee's schedule of deadlines. Application deadlines should be designed to enable Committee review and communication of decisions to students at a sufficiently early point that flexibility of schedule still exists. Extenuating circumstances may be considered at the discretion of the Program Review Committee.
7. Concentrations and minors are additional degree designations. Any credit earned for an additional degree designation **must not overlap with credit earned for another additional degree designation by more than one unit. Also, no credit-bearing activity may be triple-counted** towards degree designations or degree requirements.

Listings of Concentrations may be found in the "Department and Program Descriptions" section beginning on page 28.

MINORS

DEFINITION

A minor is a thematically-related set of academic activities leading to a degree designation in addition to but separate from that granted by the major. A minor should be available to students of any major, with the exception of a minor which overlaps with a major area to such an extent that it is not sufficiently distinct from that major. The Committee on Academic Operations (CAO) is responsible for the review of proposed minor programs and decisions regarding allowed major/minor combinations.

RULES

1. A minor requires completion of two or more units of thematically related activity. Individual departments may impose additional restrictions such as a capstone or integrative experience. Students should consult individual minor Program descriptions in Section 2 of this catalog for these restrictions.
2. It is expected that minor requirements will be structured so that all acceptable major/minor combinations can be accommodated within a normal 16 term framework.
3. A minor may include any portion of the academic program, excluding the MQP. Academic activities used in satisfying the regular degree requirements may be double-counted toward meeting **all but one unit of the minor requirements**, subject to the following restrictions:
   a. The one unit of double-counted work may include at most 1/3 unit of the IQP, 3/3 units of the Humanities and Arts Requirement, or a combination thereof.
   b. At least one unit of the minor must be free elective choices. For the social science exception see page 121.
4. The Program Review Committee for a minor area will consist of faculty members designated by the sponsoring faculty members.
5. A minor area must be proposed by a sponsoring group of faculty and must be defined by the purpose of achieving an educational goal beyond those apparent or implicit in the regular degree requirements. Student- initiated minor programs must be developed with the approval of a sponsoring group of faculty advisors. Each minor program must be reviewed by CAO for its individual merit.
6. Minors are additional degree designations. Any credit earned for an additional degree designation **must not overlap with credit earned for another additional degree designation by more than one unit. Also, no credit-bearing activity may be triple-counted** towards degree designations or degree requirements.

Minors are described in the "Program Description" section of this catalog. Minors sponsored by a department are described following the department. Others are listed in the "Interdisciplinary Minors" section. As of the printing of this catalog, the following minors have been approved:

Astrophysics; Biology; Biochemistry; Bioinformatics and Computational Biology; Business; Chemistry; Chinese Studies; Computer Science; Data Science; Drama/Theatre; Economics; Electrical and Computer Engineering; English; Entrepreneurship; Environmental and Sustainable Studies; German; Global Public Health; History; Industrial Engineering; Interactive Media & Game Development; International and Global Studies; Law and Technology; Management Information Systems; Manufacturing Engineering; Materials; Mathematics; Mechanical Engineering; Media Arts; Music; Nanoscience; Philosophy and Religion; Physics; Political Science and Law; Psychology; Robotics Engineering; Social Entrepreneurship; Social Science; Spanish; Statistics; Sustainability Engineering; System Dynamics; Writing.

Interdisciplinary or Individually Designed (ID) minors are approved by the Committee on Academic Operations (CAO).

The form needed to declare a minor or to propose an interdisciplinary or individually designed minor can be found in the Registrar's Office.

DOUBLE MAJORS

An option for some students who wish to broaden their WPI experience is the completion of two distinct majors through the double major option. The choice to pursue a double major should be made early in a student's career. No student shall complete more than two undergraduate majors.

For double majors, the diploma may list both majors (in order of preference by the student), either major, or no major as indicated by the student.

A double major should signify capacity in two distinct disciplines. Some combinations of double majors are not sufficiently distinct to merit this designation. Departments and programs decide whether any combinations of double majors overlap to such an extent as to be disallowed. As of the publication date of this catalog, the following combinations are not allowed:

- Actuarial Mathematics and Mathematical Sciences
- Aerospace Engineering and Mechanical Engineering
- Biochemistry and Chemistry
- Business and Management Engineering
- Business and Management Information Systems
- Civil Engineering and Architectural Engineering
- Civil Engineering and Environmental Engineering
- Industrial Engineering and Management Engineering with Concentration in Operations Management
- Interactive Media and Game Development Technology and Interactive Media and Game Development
- Management Engineering and Management Information Systems
- Physics and Applied Physics

Students who wish to pursue any double major should consult with faculty advisors in both majors. Exceptions to disallowed double majors must be approved by the Committee on Academic Operations.

Degree requirements for double majors are as follows

1. **Distribution Requirements.**
   The distribution requirements of each major must be met, but requirements common to both majors have to be met only once.
2. **The Humanities and Arts Requirement.**
   No modifications are made to the Humanities and Arts Requirement for double majors. All students, including majors in Humanities and Arts or International and Global Studies must satisfactorily complete the Humanities and Arts Requirement culminating in an Inquiry Seminar or Practicum.
3. **The Interactive Qualifying Project.**
   If one of the majors of a double major is in Social Science and Policy Studies, a single project bearing at least one unit credit may be used to satisfy both the MQP requirement for the SSPS major and the IQP requirement. In order to be used to satisfy both requirements, the combined social science MQP and IQP must meet the goals of both projects. It must be interactive in nature involving an aspect of technology, and must also be an application of social science knowledge and analytical techniques. In order to select a single project that satisfies both the goals of the MQP and the goals of the IQP, the decision to pursue a social science double major needs to be made fairly early in the student's career.
4. **The Major Qualifying Project.**

The MQP requirements for Double Majors may be fulfilled in either one of two ways:

- Option 1: Two distinct projects, one in each major, each of at least one unit of credit.
- Option 2: One interdisciplinary project of at least 4/3 units of credit, and having significant work associated with each major. An interdisciplinary project must be:
  - jointly advised by at least two faculty members, one associated with each of the relevant degree programs; OR
  - advised by a single faculty member who is associated with both of the relevant degree programs.

Faculty associated with each degree program are listed in Section 2 of the WPI Undergraduate Catalog.

An interdisciplinary MQP involving social science may not be used as an IQP.

The interdisciplinary MQP option takes advantage of the value of interdisciplinary work at the intersection of the two majors. Students undertaking an interdisciplinary MQP must complete an *interdisciplinary MQP approval form* in advance of project registration, and this form must be signed by all advisor(s) on the project. This form must contain a summary of the proposed project work indicating the content relating to each major. The interdisciplinary MQP option is available only at the discretion of the faculty and only when all faculty advisor(s) agree on the project content. Students planning to use this option should identify and consult with their faculty advisor(s) well before the end of their junior year.

For a double major, completion of a 4/3 unit interdisciplinary MQP completes the 1 unit MQP requirement for each major. The assignment of credit is as follows: 2/3 unit is double counted toward each major, and the remaining 2/3 unit is allocated as 1/3 unit to one major and 1/3 unit to the other major.

Note: It is anticipated that in some cases a student pursuing a double major will join a project team whose other members are pursuing a single major. The double-majoring student will bring the interdisciplinary content to the project, and this additional work will be represented by the additional credit that that student (perhaps only that student) earns, and with an enlarged report prepared by that student.

For students wishing to pursue double majors, the program audit for each intended major must be completed and certified by the review committee of each department involved. Academic activities appropriate to both majors may be counted in both majors. For the policy in the special situation of double majors involving the social sciences see the Social Science and Policy Studies department description in Section 2 and the Double Major Distribution Requirements in Section 4 of the Undergraduate Catalog.

Certain interdisciplinary MQP's and corresponding double-majors in the same department are not allowed.

Interdisciplinary MQP's with two faculty advisors: All faculty advisors have equal status in approving the final project, and a single grade is submitted for each term's work and a single project grade is submitted on the CDR form. Should an interdisciplinary MQP, once completed, be deemed acceptable as an MQP for one of the two majors, but not for the other, and/or if the faculty advisors cannot agree on a single grade after much effort to do so, the project may be considered as the MQP for a single major. This conversion can only occur with the consent of the student and the advisor(s) from the single major being selected.

PROJECTS AND RESEARCH

At the heart of the WPI Plan is student research, open-ended inquiry, and original and creative design to solve problems and to make new discoveries. All students in all majors complete two qualifying projects:

1. the Major Qualifying Project (MQP),
2. the Interactive Qualifying Project (IQP).

The *Major Qualifying Project* requires the synthesis of all previous study as well as the development of new knowledge to solve problems in the student's major field. The MQP challenges the student to perform at an advanced level, as a professional would, and to communicate the results effectively.

The *Interactive Qualifying Project* challenges students to address a problem at the intersection of science and technology with human need.

These projects are substantial and are each equivalent to at least one-fourth of an academic year's worth of effort. Most IQPs are completed at an off-campus project center in collaboration with an external sponsor.

Projects must be accepted by a project advisor before project registration can be completed. Many project opportunities come from off-campus organizations, address real-world problems and thus provide experience invaluable for seeking jobs and for professional practice. Students are also encouraged to develop their own project ideas, to identify and work with interested faculty, and to form teams to pool resources and share points of view.

RESOURCES – GETTING STARTED

There are many opportunities for students to learn about project opportunities both in the major (for the MQP) and for the IQP. Advice and links to additional resources can be found on the Undergraduate Studies web page (https://www.wpi.edu/academics/undergraduate).

AVAILABLE PROJECTS

Students may obtain information about new or ongoing projects from a variety of sources. Principal sources include discussions with other students, especially those currently involved in a project, the Projects Program web site, department offices, or their web pages. Off-campus projects are discussed annually in the fall. In the spring, Project Opportunities in eProjects 2.0 (https://eprojects.wpi.edu/) can be used as a directory of specific IQP projects or as a source of ideas for developing your own projects. Some students will find a project listed which fits their needs and interests exactly. In other cases, the listing will serve to lead students to a faculty member with whom project involvement can be negotiated. The proposals in eProjects 2.0 are updated periodically to provide an accurate listing of available projects.

Students are encouraged to check the web site of the department of their major and Project Opportunities for MQPs in eProjects 2.0 (https://eprojects.wpi.edu/), as well as consulting with their academic advisors and with faculty in their courses. In addition, academic departments hold special events where faculty present project and other research opportunities to connect with students who are currently doing research.

PROJECT ADVISOR

Academic advisors can assist students in identifying a project. They are aware of the project interests of many other faculty members, and have a list of faculty interests which will enable a student to find a faculty member who can help to develop a project idea. Faculty associated with the Interdisciplinary and Global Studies Division (IGSD) are available to assist students in interdisciplinary and interactive projects.

PROJECT PERFORMANCE AND TIME-ON-TASK

A student is normally expected to expend 15-17 hours per week on the average for each 1/3 unit of credit for project work, and expected achievement is based upon that commitment.

A project group, whether it involves one student or more, should have a minimum of one scheduled conference per week with the advisor(s). Additional time should be scheduled when the effort exceeds 1/3 unit per student or when more students are involved.

Students should be prepared to submit interim project reports to the advisor each week. Students are also encouraged to complete a proposal at the beginning of the project activity to define the scope and timeline for completion of the effort. In addition, oral reports may be required as determined by the advisor. At the end of the project, a report must be prepared to the satisfaction of the project advisor. For projects sponsored by off-campus organizations, both a written and oral report for the sponsors is normally expected.

QUALIFYING PROJECT GRADING

The Faculty of WPI has endorsed the following grading guidelines for qualifying project activity:

1. Each term a student is registered for a qualifying project, the student receives a term grade reflecting assessment of his or her accomplishments for that term.
2. Upon completion of a project, each student will receive an overall project grade (also known as the "CDR grade," since it certifies completion of the degree requirement) reflecting his or her individual overall accomplishments for the project.
3. The term grades and the overall project grade reflect both the ***products*** of the project (e.g., results, reports, etc.) and also the ***process*** by which they were attained. The term grades and the overall project grade may be different.

The following are some characteristics that faculty should use in communicating expectations and evaluating the quality of each student's project work.

The degree to which the student:

- developed effective or creative goals or approaches,
- demonstrated initiative and originality,
- showed depth and critical thought in analysis,
- produced high quality results,
- took the lead in discussion, planning, and analysis,
- produced a clear, professional-level report with excellent drafts along the way,
- anticipated work that needed to be done and completed it in a timely manner, and
- worked to advance the success of the team.

For both terms and overall project, the available grades and interpretations are:

A: This grade denotes *excellent work* that attains all of the project goals and learning outcomes. The product and process of this work meet all of the expectations and exceed them in several areas.

B: This grade denotes *consistently good work* that attains the project goals and learning outcomes. The product and process of this work meet but generally do not exceed all of the expectations.

C: This grade denotes *acceptable work* that partially attains project goals and learning outcomes. The product and process of this work meet some but not all expectations.

SP: This grade denotes *satisfactory progress* and certifies sufficient accomplishments to earn credit for that term. Faculty who assign this grade should provide clear feedback to the student regarding his or her progress during the term. The use of the SP grade is discouraged except in circumstances where the faculty member is unable to judge the quality of the work, yet can attest that the granting of credit is appropriate. This is a temporary grade and must be replaced by a permanent grade consistent with the criteria outlined above by, if not before, the end of the project.

NR: This grade denotes work that did not attain the project goals or learning outcomes and is *insufficient for registered credit*. Both product and process were inconsistent with acceptable project work at WPI as outlined above.

NAC: This grade is reserved for *performance that is unacceptable*. It might mean that a student's performance (or lack of it) has seriously impeded group progress, or it has embarrassed the group, a project sponsor, or WPI. Note that this grade remains on the transcript.

4. Project goals should be established and clearly articulated early in the project. This may be done in the form of a formal project proposal. Learning outcomes for the qualifying projects have been established by the faculty and are published in the undergraduate catalog.
5. Project advisors should clearly convey in writing their expectations for learning and performance to project students at the start of the project, and provide students with substantive feedback on a regular basis during the project.

ELECTRONIC PROJECT SUBMISSION

WPI requires that all undergraduate students submit their Interactive Qualifying Project (IQP) and Major Qualifying Project (MQP) electronically (wpi.edu/+eprojects).

Students must be registered for a minimum of 1/6 unit of qualifying project credit in the term in which the final project report is submitted. An eProject must be submitted via the web site, wpi.edu/+eprojects, following the steps outlined there.

No matter which format is used to create the original report document (Microsoft Word, LaTeX or other), the final report must be converted to a PDF format in order to be submitted as an eProject. The final PDF is required, and additional related files such as simulations, computer programs, multimedia, and data sets may be submitted as a component of the project. Guidance on eProject report formatting and file formats for the final report and any supplementary files is provided within the online submission process.

Every eProject must include a title page and must follow the formatting guidelines described at wpi.edu/+eprojects.

The final project report should be carefully proofread. Once the submitted project has been approved by the advisor and released to WPI's digital repository (Digital WPI) by the Registrar's Office, it is considered an academic record and cannot be edited.

The deadline for the submission of the initial report draft and the final document may be established at the discretion of the project advisor. Drafts and reports need ***not*** be accepted by the advisor after the established deadline.

A project that is completed by a team of students, except in extenuating circumstances, will submit ONE project report from the group. After the MQP or IQP team submits the final version of the project report, the advisor must review the work and approve or reject it online at wpi.edu/+eprojects.

A completed electronic Completion-of-Degree-Requirement (eCDR) form, must be printed for signature by each student and signed individually by the advisor as the final step in the submission process. The eCDR form must be submitted in person by the project advisor or a member of the academic department of the advisor to the Office of the Registrar by no later than the tenth day of the next academic term.

A student who has filed an application to receive their degree in May must submit a completed eCDR to the Office of the Registrar by the last Thursday in D-term.

GROUP QUALIFYING PROJECT EFFORTS

Students meeting a qualifying project degree requirement by participation in a group, or team effort, will submit, at the discretion of the project advisor, either a single, comprehensive written report from the group, or individual written reports from each member of the group. A single, comprehensive written report must, however, include some means by which each individual's contribution to the group effort may be clearly identified. This identification may take the form of an "authorship page," simply a list of individual chapters and their respective authors, or of a prefacing statement in which each contributing group member is named as having carried out one or more specific tasks within the overall project effort.

In the case where one or more students leave an ongoing group project after having contributed at least one unit each of project effort, those students, again at the discretion of the project advisor, will submit either a single written report or individual written reports in satisfying the qualifying project documentation requirement. The same means of identifying individual contributions will be employed as described above.

DISSEMINATION OF PROJECT REPORTS

Completed project reports are made available to the public through Digital WPI, managed by WPI's Gordon Library (https://www.wpi.edu/library/digital-wpi).

MQPs and IQPs completed for off-campus agencies are usually distributed within the sponsoring agency by the agency project liaison. A project report may be redacted or restricted from public viewing for a defined period of time, if it contains confidential or proprietary information of a sponsoring agency.

Students are responsible for keeping personal copies of project reports for their own permanent professional records. In this way, reports can be reviewed for later use, and incorporated into a professional portfolio.

Thus, MQPs and IQPs are best viewed as research reports which establish good professional practices as well as being potential sources for further study and research.

PAY AND CREDIT (for students working on sponsored projects)

A student may receive pay for work associated with a registered project under the following conditions:

1. The work done for pay is clearly distinguished from the work defined for academic credit for the project. This distinction must be clearly articulated in a conflict of interest statement signed by all participating parties before the project begins.
2. Results obtained from paid or unpaid work performed while students are not registered for project credit at WPI may be used in projects only after consultation with the project advisor. When possible, such consultation should take place before work begins.

The qualifying project in the major field of study should demonstrate application of the skills, methods, and knowledge of the discipline to the solution of a problem that would be representative of the type to be encountered in one's career. The project's content area should be carefully selected to complement the student's total educational program. In defining the project area within which a specific topic is to be selected, the student and academic advisor should pay particular attention to the interrelationships that will exist between the bodies of knowledge represented by courses, independent studies, and Preliminary Qualifying Projects; and by the Interactive Qualifying Projects.

MQP activities encompass research, development, and application, involve analysis or synthesis, are experimental or theoretical, emphasize a particular subarea of the major, or combine aspects of several subareas. In many cases, especially in engineering, MQP's involve capstone design activity. Long before final selection of a project topic, serious thought should be given as to which of these types of activities are to be included. Beyond these considerations, the MQP can also be viewed as an opportunity to publish or to gain experience in the business or public sectors.

Off-campus MQPs are also very valuable for access to state-of-the-art resources and contacts for future professional work.

GETTING STARTED ON AN MQP

Project topics are originated by students, faculty, or practicing professionals participating in WPI's off-campus project programs. A faculty member in each academic department acts as Project Coordinator for all majors within the department. The Project Coordinator has assembled MQP topic descriptions being proposed and has identified the faculty who will serve as project advisors for each topic. All project opportunities-MQP, IQP, PQP, on-campus originated and off-campus originated are made available to the student body through a planned information-sharing program of activities during C and D terms of the academic year prior to the start of the project.

PROJECT PROPOSALS

Students are strongly encouraged to begin their MQPs with a project proposal. A detailed guide to preparing project proposals is available in department offices or on the Projects Program web page (https://www.wpi.edu/academics/Projects/).

MQP LEARNING OUTCOMES

By completing their MQP, WPI students will achieve the following learning outcomes at a level at least equivalent to that of an entry level professional or graduate student.

Students who complete a Major Qualifying Project will:

1. apply fundamental and disciplinary concepts and methods in ways appropriate to their principal areas of study.
2. demonstrate skill and knowledge of current information and technological tools and techniques specific to the professional field of study.
3. use effectively oral, written and visual communication.
4. identify, analyze, and solve problems creatively through sustained critical investigation.
5. integrate information from multiple sources.
6. demonstrate an awareness and application of appropriate personal, societal, and professional ethical standards.
7. practice the skills, diligence, and commitment to excellence needed to engage in lifelong learning.

Specific disciplinary programs may add additional MQP outcomes, such as design or mathematical skills or teamwork, as appropriate.

MQP PROJECT CENTERS

Each project center has a WPI faculty member as the director, well-defined procedures for completing project work, and selective admissions processes. The Centers tend to be highly structured and require superior performance.

At the present time, the WPI project center close to campus is:

- University of Massachusetts Medical School Project Center/ Tufts University Cummings School of Veterinary Medicine.

See also page 19 for residential Project Centers at a distance from WPI.

UNIVERSITY OF MASSACHUSETTS MEDICAL SCHOOL PROJECT CENTER/TUFTS UNIVERSITY CUMMINGS SCHOOL OF VETERINARY MEDICINE

Major qualifying projects are available at nearby University of Massachusetts Medical School (UMMS) and Tufts University Cummings School of Veterinary Medicine (TUCSVM) for students from many disciplines on campus. These institutions are nationally recognized for research and medicine and offer project opportunities over a wide range of research areas. Students performing projects at these centers work in cutting edge research programs and typically interact with graduate and post-doctoral researchers to solve real-world problems.

It is recommended that students spread their projects over the entire academic year. Students from any major interested in project opportunities should contact Dr. Destin Heilman in the department of Chemistry and Biochemistry.

At WPI, students are expected to develop an understanding of how science and technology are embedded in the fabric of society. The Interactive Qualifying Project (IQP) challenges students to address a problem that lies at the intersection of science or technology with society. During the IQP, students work in interdisciplinary teams, often with an external sponsoring organization, to develop solutions to real world problems. In doing so, students learn something about the role of science and technology, its impact on society, its place in meeting human needs and human efforts to regulate, control, promote and manage our changing technologies. The IQP is equivalent to three courses, typically undertaken in a student's junior year. It can be completed over three terms, or as a full course load for a student for one term, and it can be completed on-campus, or at one of our many residential project centers in the U.S. and abroad. For more on the IQP see the websites of the Interdisciplinary and Global Studies Division (IGSD) at https://www.wpi.edu/academics/igsd/iqp.html. For more on the IQP and study abroad, see the Global Projects Program website: https://www.wpi.edu/academics/igsd/gpp.html. Completed IQP reports are electronically archived and made available to the public through Digital WPI, managed by WPI's Gordon Library https://www.wpi.edu/library/digital-wpi).

IQP LEARNING OUTCOMES

The Faculty adopted the following statement defining learning outcomes for the IQP. Successful completion of an IQP is an important element in helping students achieve WPI's overall undergraduate learning outcomes.

Students who complete an Interactive Qualifying Project will:

1. Demonstrate an understanding of the project's technical, social and humanistic context.
2. Define clear, achievable goals and objectives for the project.
3. Critically identify, utilize, and properly cite information sources, and integrate information from multiple sources to identify appropriate approaches to addressing the project goals.
4. Select and implement a sound methodology for solving an interdisciplinary problem.
5. Analyze and synthesize results from social, ethical, humanistic, technical or other perspectives, as appropriate.
6. Maintain effective working relationships within the project team and with the project advisor(s), recognizing and resolving problems that may arise.
7. Demonstrate the ability to write clearly, critically and persuasively.
8. Demonstrate strong oral communication skills, using appropriate, effective visual aids.
9. Demonstrate an awareness of the ethical dimensions of their project work.

PREPARING FOR AND FINDING AN IQP

Students are encouraged to view the IQP as a learning opportunity – a chance to gain knowledge outside their major field – while working with others to solve open-ended, complex problems. The best approach is to consult with one's academic advisor and select courses to be taken in the first and second year at WPI that can provide a foundation for an IQP in the junior year. Often project preparation involves developing an understanding of the social sciences and humanities, as the concepts and analytical techniques of these disciplines are important in understanding the social context of science and technology. In addition, students enrolled in the Global Projects Program will be expected to complete a course devoted to project preparation in advance of their travel.

Project topics originate with external organizations, faculty and students. Students who complete IQPs at a residential project center through the Global Projects Program work on project topics identified by external sponsoring organizations. Students can explore these opportunities in eProjects 2.0 (eprojects.wpi.edu) and at the Global Opportunities Fair organized each September by the Interdisciplinary and Global Studies Division (IGSD, https://www.wpi.edu/+igsd). Students completing projects on campus are encouraged to seek faculty members that share their interests to advise projects. Faculty interested in advising specific IQPs will post their project topics in eProjects 2.0 (eprojects.wpi.edu). The IGSD also hosts an On-Campus Project Opportunities Fair each March where students can meet faculty advisors to discuss projects being offered on campus during the following year.

The IGSD offers administrative support for project activities. Students are welcome to seek further assistance from the staff on the second floor of the Project Center.

WHAT ARE IQPS ABOUT? SCIENCE, TECHNOLOGY AND SOCIETY

A detailed explanation of the IQP and its options can be found at https://www.wpi.edu/academics/undergraduate/interactive-qualifying-project. Proposed projects can be located in eprojects.wpi.edu. IQP (and MQP) projects are searchable in Digital WPI (https://www.wpi.edu/library/digital-wpi).

GLOBAL PROJECTS PROGRAM

The Global Projects Program, overseen by the Interdisciplinary and Global Studies Division, offers WPI students the opportunity to complete a project at one of WPI's off-campus project sites. Some centers are residential, with students traveling to and living on site for an entire term, while others offer the opportunity to complete an off-campus project in Worcester, Boston, or other nearby communities. Project work conducted at these sites provides teams of students with extraordinary opportunities to learn by solving real-world problems provided by industry, non-profit, non-governmental or government agencies.

The application process for these programs begins in the fall with the Global Fair. At the Fair, IQP, MQP, HUA and exchange program directors will be available to talk with students. Students should apply in Term A of the year preceding the year in which they would like to participate. Further information is available at the Interdisciplinary and Global Studies Division in the Project Center or through the Program Guide: https://www.wpi.edu/project-based-learning/global-project-program/program-guide

Application processes are competitive and accepted students must complete a series of pre-departure orientations and submit required paperwork to be eligible to travel.

All students accepted to an off-campus IQP Center will be registered for the preparation courses (ID 2050 and PQP) in the term immediately preceding their planned term of travel. Students must be making satisfactory progress in their academic coursework in order to participate. Students are highly discouraged from overloading during the preparatory term and may only overload during the project term with the permission of their project advisors.

Prior to leaving campus for a project program site, each student is required to complete a project registration form as described on page 217.

OFF-CAMPUS PROGRAMS

All programs offer students the opportunity to complete a project in one term of full-time work. Advance preparation is required. Faculty advisors are in residence at IQP sites and some Humanities and Arts and MQP sites.

REGION	PROJECT CENTER	TYPE	E	A	B	C	D	SITE DIRECTOR(S)
Africa & Middle East	Cape Town, South Africa	IQP			■			Scott Jiusto & Gbeton Sommasse
Africa & Middle East	Kyebi, Ghana	IQP/MQP				■		Rob Krueger
Africa & Middle East	Rabat, Morocco	IQP				■		Mohamed Brahimi & Tahar El-Korchi
Africa & Middle East	Rabat, Morocco	HUA				■		Rebecca Moody
Africa & Middle East	Windhoek, Namibia	IQP		■			■	Creighton Peet
Africa & Middle East	Israel (Eilat)	IQP				■		Isa Bar-On
Africa & Middle East	Israel (Multiple Cities)	MQP				■		Isa Bar-On
Asia	Bangkok, Thailand	IQP				■		Esther Boucher & Rick Vaz
Asia	Beijing, China	IQP/MQP	■					Jianyu Liang
Asia	Hangzhou, China	IQP			■			Wen-Hua Du & Jennifer Rudolph
Asia	Hong Kong, China	IQP				■		Creighton Peet
Asia	Japan (Kypto)	IQP		■				Jennifer deWinter
Asia	Japan (Multiple Cities)	HUA	■					Jennifer deWinter
Asia	Japan (Osaka/Kyoto)	MQP		■				Jennifer deWinter
Asia	Mandi, India	IQP					■	Ingrid Shockey
Asia	Yerevan, Armenia	IQP					■	Michael Aghajanian
Europe	Berlin, Germany	IQP					■	Dan Dimassa, Katherine Foo & Stephan Sturm
Europe	Bucharest, Romania	IQP					■	Bogdan Vernescu & Rodica Neamtu
Europe	Copenhagen, Denmark	IQP		■		■		Holly Ault & Peter Hansen
Europe	France (Multiple Cities)	Exchange		■	■	■	■	Norman Wilkinson
Europe	Konstanz, Germany	Exchange	■				■	Ulrike Brisson
Europe	London, England	IQP				■	■	Dominic Golding
Europe	London, England	HUA	■					Esther Boucher
Europe	Lyon, France	IQP	■					Peter Hansen & Fabienne Miller

REGION	PROJECT CENTER	TYPE	E	A	B	C	D	SITE DIRECTOR(S)
Europe	Moscow, Russia	IQP					■	Svetlana Nikitina
Europe	Nancy, France	MQP				■		Steve Kmiotek
Europe	Reykjavik, Iceland	IQP		■				Aaron Sakulich
Europe	Stockholm, Sweden	MQP		■	■			Holy Ault
Europe	Thessaloniki, Greece	IQP					■	Bob Hersh
Europe	Tirana, Albania	IQP			■			Bob Hersh & Peter Christopher
Europe	Venice, Italy	IQP			■			Fabio Carrera
Europe	Worcester, England	IQP					■	Rob Krueger
Europe	Zurich, Switzerland	IQP/MQP					■	Nancy Burnham
North America	Bar Harbor, ME	IQP	■					Fred Bianchi
North America	Boston, MA	IQP		■				Paul Mathisen & Seth Tuler
North America	Gallo-Modesto, CA	MQP				■		David DiBiasio & Nikolaos Kazantzis
North America	Glacier National Park, MT	IQP		■				Fred Bianchi
North America	Hilo, Hawaii	IQP				■		Lauren Mathews
North America	MIT Lincoln Lab-Lexington, MA	MQP		■				George Heineman
North America	MITRE-Bedford, MA	MQP		■				Andrew Clark & Shamsnaz Virani Bhada
North America	Nantucket, MA	IQP			■			Dominic Golding
North America	San Juan, Puerto Rico	IQP					■	Lauren Mathews
North America	Santa Fe, NM	IQP		■				Fabio Carrera
North America	Silicon Valley, CA	MQP				■		Mark Claypool
North America	Stantec-Boston, MA	MQP			■			Suzanne LePage
North America	Wall Street/FinTech	MQP			■			Robert Sarnie
North America	Washington, DC	IQP			■			Kent Rissmiller
North America	Water Resource Outreach Center	IQP					■	Corey Dehner & Paul Mathisen
North America	Worcester, MA	IQP	■		■	■	■	Laura Roberts
South & Central America	Monteverde, Costa Rica	IQP				■		Melissa Belz
South & Central America	Panama City, Panama	IQP/MQP		■				Aaron Sakulich & Tahar El-Korchi
South & Central America	San Jose, Costa Rica	IQP				■		Melissa Belz
South & Central America	Asuncion, Paraguay	IQP					■	Rob Traver
South & Central America	Buenos Aires, Argentina	HUA	■					Aarti Smith Madan
South & Central America	Campinas, Brazil	MQP				■		Mike Timko
South & Central America	Cuenca, Ecuador	IQP				■	■	Laureen Elgert & Courtney Kurlanska
South Pacific	Melbourne, Australia	IQP			■	■	■	Lorraine Higgins & Steve McCauley
South Pacific	Wellington, New Zealand	IQP				■		Mike Elmes & Ingrid Shockey

INDIVIDUALLY SPONSORED RESIDENTIAL PROJECTS (ISRPs)

Through the Individually Sponsored Residential Projects (ISRP) process, faculty may design custom off-campus projects in addition to the established options available at WPI Project Centers. **ISRPs are subject to an approval process through the IGSD that includes routine planning and risk management protocols employed for the Global Projects Program.**

Consult the Global Portal at https://www.wpi.edu/+globalportal for ISRP Process Deadlines. Please contact IGSD at global@wpi.edu with any questions about the ISRP process.

INDIVIDUALLY SPONSORED ON-CAMPUS IQP PROGRAMS

CENTER FOR SUSTAINABLE FOOD SYSTEMS

Co-Directors Prof. Bob Hersh and Elisabeth (Lisa) Stoddard

In this set of on-campus IQPs students will work collaboratively with community groups, public health agencies, farmers, ecological designers, and organizations involved in regional food planning to: 1) improve access to healthy food in neighborhoods in Worcester, central Massachusetts, and regionally; 2) create closer links among food system activities (production, processing, distribution, consumption, waste disposal) 3) catalyze food business opportunities (e.g.,urban farms, food processing, community kitchens, composting services) in these communities; and 4) collaborate with farmers on innovative designs for small scale food production (e.g., bioshelters, grain harvesters, vertical farms).

Recent projects include designing and building a commercial bike trailer out of recycled and 3D printed materials for an urban farmer in Boston and improving winter heating and lighting systems using solar to increase winter egg production on a farm in western MA. The Center also works with students on ongoing volunteer community projects, including growing seedlings in the university's green house for the two organic farms and dozens of school and community gardens run by the Regional Environmental Council. For more information, please contact Prof. Elisabeth (Lisa) Stoddard (eastoddard@wpi.edu).

ENERGY SUSTAINABILTY PROJECT CENTER

Director, Professor Paul Mathisen, Kaven Hall 209E

This center supports and helps to coordinate project work (both MQPs and IQPs) in all aspects of energy and across all areas of academic inquiry at WPI. A goal is to promote the use of innovative technologies and approaches to meet on-campus, regional, and global energy challenges. The principles of sustainability, with consideration to economics, the environment, and social justice, are emphasized in all of the Center's activities. The Center's objectives are to support and to facilitate the organization of project teams and advisors to address problems involving sustainability and energy. Areas of interest range from traditional and renewable forms of energy to the use of systems approaches to address the relationships between energy and societal needs such as buildings, transportation, food and water. Center activities include the following: communication of WPI's activities in the energy area both internally and externally; establishment of a clearinghouse for project topics and the formation of project teams; organization of a forum for discussion of major energy-related topics, highlighting excellent energy-related projects; and identifying externally-sponsored projects. For more information contact Prof. Paul Mathisen (mathisen@wpi.edu).

STEM EDUCATION PROJECT CENTER

"Talent is equally distributed but opportunity is not." – Leila Janah

This often-quoted phrase is the heart of this Project Center and focuses on PreK-12 Science, Technology, Engineering, and Mathematics (STEM) Education. With the goal of improving PreK-12 STEM education opportunities for all children, our objectives include: 1) providing engaging and inclusive STEM activities to diverse audiences, 2) examining the educational opportunity gaps in different contexts, and 3) supporting informal and formal educators in STEM. Some projects may be to design, develop, and test hands-on, standards-aligned, PreK-12 STEM; to examine STEM education in a global context; and to develop sustainable relationships between WPI and local non-profits around STEM opportunities. In addition, the teaching practicum requirement in the Teacher Preparation Program is typically done as an IQP during A&B or C&D terms. These projects (MQPs and IQPs) are in partnership with the STEM Education Center at WPI and PreK-12 schools, afterschool programs, non-profits, and educators. Faculty are invited to bring projects under the STEM Education Project Center. For more information, please contact Kathy Chen (kcchen@wpi.edu) and go to https://www.wpi.edu/+stem.

SUSTAINING WPI PROJECT CENTER

Co-Directors, Suzanne LePage and Derren Rosbach

There is a great deal of interest in enhancing the sustainability of WPI – both as an institution and as a campus. The Sustaining WPI Project Center was developed to support and coordinate project work (primarily IQPs) developed around these interests. Project topics are proposed by the project teams based on their sustainability interests and in coordination with faculty advisors and the WPI Office of Sustainability. The intent is to address all aspects of sustainability as outlined in the WPI Sustainability Plan: campus facilities, the educational curriculum, research and scholarship, as well as civic engagement. The Center sponsors IQPs in D-term each year with student preparations beginning in C-term. For more information contact Suzanne LePage (slepage@wpi.edu).

OVERVIEW

The Humanities and Arts Requirement empowers students to meet the broad educational goals of WPI. The balance between technological and humanistic education and the emphasis on inquiry-based approaches to student learning have been and remain hallmarks of a WPI education. In concert with WPI's other degree requirements, the Humanities and Arts Requirement embodies the institute's definition of an educated person. The Humanities and Arts Requirement engages students with theory and practice – *Lehr und Kunst* – through the following educational goals.

GOALS OF THE HUMANITIES AND ARTS REQUIREMENT

- to introduce students to the breadth, diversity, and creativity of human experience as expressed in the humanities and arts;
- to develop students' ability to think critically and independently about the world;
- to enhance students' ability to communicate effectively with others in a spirit of openness and cooperation;
- to enrich students' understanding of themselves;
- to deepen students' ability to apply concepts and skills in a focused thematic area through sustained critical inquiry;
- to encourage students to reflect on their responsibilities to others in local, national and global communities;
- to kindle in students a life-long interest in the humanities and arts.

MEETING THE REQUIREMENT

Students fulfill the humanities and arts degree requirement by completing two units of work consisting of five student-selected courses followed by a 1/3 unit Inquiry Seminar or Practicum (HU 3900, HU 3910, or equivalent). In selecting the courses, students must complete depth and breadth components of the requirement, as described below. *All 5 HUA courses must be completed before beginning the Inquiry Seminar or Practicum.* At the end of the Inquiry Seminar or Practicum, every student will submit a completion-of-degree requirement form (CDR) to certify completion of the requirement.

DEPTH COMPONENT:

The WPI Plan calls for students to develop a meaningful grasp of a thematic area of the humanities and arts. *To ensure this depth, students complete at least three courses of thematically-related work prior to a culminating Inquiry Seminar or Practicum in the same thematic area.* Thematically-related work can be achieved in two ways:

1. Focusing on one of the following disciplines or disciplinary areas:
   - art/art history (AR)
   - music (MU)
   - drama/theatre (EN/TH)
   - literature and writing/rhetoric (EN, WR, RH)
   - history and international and global studies (HI, HU, INTL)
   - philosophy and religion (PY, RE)

   Paths for language study are described below.
2. Defining the thematic area across disciplines or disciplinary areas in consultation with a Humanities and Arts faculty member.

To ensure that students develop a program of increasing complexity, at least one of the three thematically-related courses that precede the Inquiry Seminar or Practicum must be at the 2000-level or above. Students are strongly encouraged but not required to include a 3000-level course within their depth component. The structure of the requirement remains flexible so that students will become intentional learners as they select a sequence of thematically-related courses.

BREADTH COMPONENT:

To ensure intellectual breadth, before taking the final Inquiry Seminar or Practicum, students must take at least one course outside the grouping in which they complete their depth component. To identify breadth, courses are grouped in the following manner:

- art/art history, drama/theatre, and music (AR, EN/TH, MU);
- languages (SP, GN, ISE, AB, CN);
- literature and writing/rhetoric (EN, WR, RH);
- history and international and global studies (HI, HU, INTL);
- philosophy and religion (PY, RE).

WPI offers a flexible curriculum to entrust students with a significant amount of choice and responsibility for planning their own course of study. At the same time, WPI requires students to take at least one course outside the depth area in order to provide exposure to more than one disciplinary approach within the arts and humanities, which include the creativity of the fine and performing arts, modes of communication in languages and literature, and the cultural analysis of the past and present. Students are encouraged to experiment and to take courses in more than one group outside the depth area if they wish. By providing exposure to multiple areas, the breadth component encourages students to appreciate the fundamental unity of knowledge and the interconnections between and among diverse disciplinary fields.

The one exception to this breadth requirement is that students may take all six courses in a foreign language.

DEPTH AND BREADTH COMPONENTS IN FOREIGN LANGUAGES:

Development of proficiency in a language necessitates sustained engagement in the language beyond the elementary and intermediate level. Language instruction is broadly interdisciplinary and includes elements of the history, literature, and culture of a particular language area. A student in languages must still meet the depth component of the requirement by taking 6 courses in the language, one of which is approved as the final Inquiry Practicum or Seminar. Additional information about options for the Inquiry Practicum or Seminar in Chinese (CN), English for Non-Native speakers (ISE), German (GN) and Spanish (SP) can be found later in this section. A student who begins language study is not compelled to remain in that subject, but could choose to switch to another subject of study and complete the depth component in another thematic area.

INQUIRY SEMINAR OR PRACTICUM

The culmination of the depth component of the Humanities and Arts Requirement is an inquiry seminar or practicum. The educational goals for the seminar or practicum are the same regardless of the format.

OBJECTIVES OF THE INQUIRY SEMINAR OR PRACTICUM:

- *Critical inquiry*: to develop each student's ability to apply concepts and skills learned in the humanities and arts, the seminar/practicum offers opportunities to engage in sustained critical inquiry, analysis, or problem-solving in a focused thematic area.
- *Research and investigation:* to engage students in research, discovery, creativity, or investigation, the seminar/practicum provides opportunities for students actively and critically to seek and evaluate new information and insights using multiple sources. These opportunities need not necessarily be research papers.
- *Communication and writing*: to develop each student's ability to communicate effectively both orally and in writing, the seminar/practicum includes discussion of appropriate communications skills and provides opportunities to revise written work after receiving feedback from the instructor.
- *Intellectual independence*: to foster independence of thought, the seminar/practicum offers significant opportunities for individual, self-directed work.
- *Conversation and dialogue*: to promote individual reflection and the appreciation of diverse perspectives, the seminar/practicum consists of classroom activities other than traditional lecture to encourage discussion and collaborative learning in a spirit of openness, cooperation, and dialogue with peers. The thematic focus, structure, and assignments for each seminar or practicum are to be determined by each individual instructor to achieve these goals.

INQUIRY SEMINAR

The Inquiry Seminar, usually taken in the sophomore year, represents the culmination of the Humanities and Arts Requirement. The Seminar provides an opportunity for students to explore a particular topic or theme in the humanities in greater depth. The Seminar has two primary goals. The first is to foster independence of student thought, typically through some form of self-directed activity. The second is to encourage a cooperative, dialogic approach to inquiry, through open exchanges with peers in a small, intensive classroom setting (typically 12 students or fewer). Students learn how to frame questions in the context of a particular discipline or field of study, and to explore or investigate problems using methods appropriate to work in the humanities and arts.

As the student's capstone experience in the humanities and arts, the Inquiry Seminar is intended to help students take their knowledge of the humanities to a higher level. The purpose of the Inquiry Seminar, therefore, is not to provide a broad survey or general introduction to a given discipline, but to provide a structured forum in which students might approach a specific humanities-related problem or theme at a deeper, more sustained level of intellectual engagement than would normally be possible within a traditional course setting. The pedagogical idea behind the Inquiry Seminar is that work in the humanities and arts is at once an intensely personal enterprise, in which the individual freely draws on her or his own particular interests, abilities, passions, and commitments, and at the same time a form of ethical community in which the practitioner is always in conversation with and accountable to others.

While the specific content and requirements of the Inquiry Seminar vary from instructor to instructor, all Inquiry Seminars incorporate self-directed learning as a significant part of the curriculum. It is the department's expectation, therefore, that by the time they enroll in the Seminar, students should have sufficient background in the humanities and arts to be able to work independently and to pose questions of their own. Students will be asked to research and write a term paper, to assemble a portfolio of writings or exercises, or otherwise to demonstrate their ability to pose a question of relevance to humanities inquiry, and to answer it. At the same time, the Seminars are designed to foster an atmosphere of intellectual collaboration and discovery. Students are required to participate fully in seminar discussion, to share the results of their own research or activities, and to engage the ideas and interests of their peers in a constructive and collegial way.

PRACTICUM IN HUMANITIES AND ARTS

Students in the performing arts have the option to complete their Humanities and Arts sequence with an Inquiry Practicum in music or drama/theatre. A practicum shares the same goals and objectives of an inquiry seminar but provides students with a production/performance experience which emphasizes the hands-on, practical application of skills and knowledge gained from previous Humanities and Arts courses. Samples of practicums in music include composing, arranging, or performing a solo recital. Drama/Theatre students may choose to act, direct, or design for a campus production. In addition to weekly meetings, students may be required to attend rehearsals and performances. The design of the final project is determined through conversations between instructors and students. Due to the unique nature of the practicum, permission of the instructor is required to enroll in a practicum.

LANGUAGES: PRACTICUM OR SEMINAR

Students in languages may complete the Humanities and Arts Requirement in one of the following three ways:

1. *Practicum in the sixth and final course in a language*. The practicum will include evaluative components or exams to demonstrate overall language skills in four areas: listening, speaking, reading, and writing. The practicum will require students to demonstrate breadth of cultural knowledge of the language area. (Examples of practicum courses: CN 2544, CN 3544, GN 3512, GN 3515; SP 3522; SP 3527)
2. *Advanced language seminar after five previous courses in the language*. The seminar will explore a thematic topic and provide opportunities for individual inquiry. (Seminar examples: GN 3513, GN 3514; SP 3523, SP 3524, SP 3525, SP 3526, SP 3528, SP 3529, SP 3530, SP 3531)

3. *Advanced language seminar after advanced-level language courses combined with courses from other areas of study.* Students who demonstrate basic oral, written, and cultural knowledge of a language in a placement test at the advanced level may combine courses from other areas for their requirement. (Seminar examples are the same as option 2.) International students who are non-native speakers may take a combination of ISE and WR courses and fulfill the HUA requirement by taking a 3000-level or above ISE/WR project-based course.

Option 1 and 2 require students to take six courses in a language. For example, in option 1, a student without prior language training might begin with GN 1511 Elementary German I and conclude with a practicum in GN 3512 Advanced German II. In option 2, for example, a student might start with SP 2521 Intermediate Spanish I followed by five Spanish courses which culminate in one of the designated seminars. In option 3, students who demonstrate knowledge of the language at the advanced level may mix courses from other areas in their course sequence. For example, a student might take two courses from history, philosophy, music, etc. along with four advanced Spanish courses which would culminate in a designated seminar. Students in the English language track might begin with three ISE courses, take one WR course, one from history, and conclude with a 3000-level ISE/WR course. Students in all three options for languages would be required to submit the same materials to demonstrate completion of the requirement as students whose culminating experience was an inquiry seminar or practicum in another area of the Humanities and Arts.

HUA FACULTY ARRANGED BY DISCIPLINARY GROUP

Art/Art History (AR)
Roshanak Bigonah (AR)
Jennifer deWinter (AR)
Adryen Gonzalez (AR)
Edward Gutierrez(AR)
Marie Keller (AR)
Jo Ellen Reinhardt (AR)
Joshua Rosenstock (AR)
M. David Samson (AR)

Music (MU)
Scott Barton (MU)
Fred Bianchi (MU)
V.J. Manzo (MU)
Douglas Olsen (MU)
Joshua Rohde (MU)
Douglas Weeks (MU)
Brent Wetters (MU)

Drama/Theatre (TH)
Patrick Crowe (TH)
Despoina Giapoudzi (TH)
Kathryn Moncrief (TH)

Languages (AB, CN, GN, SP)
Joe Aguilar (SP)
Mohamed Brahimi (AB)
Esther Boucher-Yip (ISE))
Ulrike Brisson (GN)
Althea Danielski (ISE)
Daniel DiMassa (GN)
Wen-Hua Du (CN)
Mohammed El Hamzaoui (AB, ISE)
Margarita Halpine (SP)
Aarti Madan (SP)
Ingrid Matos-Nin (SP)
Angel Rivera (SP)
Huili Zeng (CN)

Literature/Writing (EN, ISE, WR)
Joe Aguilar (EN, WR)
Esther Boucher-Yip (ISE, WR)
Kristin Boudreau (EN)
Joel Brattin (EN)
Jim Cocola (EN)
Althea Danielski (ISE, WR)
Jennifer deWinter (WR)
Mohammed El Hamzaoui (ISE, WR)
Michelle Ephraim (EN)
Brenton Faber (WR)
Joshua Harmon (EN, WR)
Lorraine Higgins (WR)
Shana Lessing (WR)
Kevin Lewis (WR)
Ryan Madan (WR)
Katherine McIntyre (EN, WR)
Svetlana Nikitina (EN, HU)
Lance Schachterle (EN)
Yunus Telliel (WR)

History/International and Global Studies (HI, HU, INTL)
Bland Addison (HI, INTL)
Steven Bullock (HI)
Constance Clark (HI)
Joseph Cullon (HI)
Lindsay Davis (HI)
Holger Droessler (HI, INTL)
John Galante (HI, INTL)
James Hanlan (HI)
Peter Hansen (HI, INTL)
Shana Lessing (HI, INTL)
Jennifer Rudolph (HI, INTL)
William San Martin (HI, INTL)
David Spanagel (HI)

Philosophy/Religion (PY, RE)
Bethel Eddy (PY, RE)
Roger Gottlieb (PY, RE)
Jennifer McWeeny (PY)
Rebecca Moody (PY, RE)
Geoff Pfeifer (PY, RE)
John Sanbonmatsu (PY)

AP CREDIT POLICY

The Humanities and Arts Department will accept a maximum of 1/3 unit of AP credit towards the Humanities and Arts requirement. Students who score a 4 or 5 on the AP test in German or Spanish automatically receive 1/3 unit of credit in the language, provided they do not begin German or Spanish study at WPI with Elementary German I (GN 1511) or Elementary Spanish II (SP 1523). Students who score a 4 or 5 on the AP test in studio art may be eligible for HUA credit, subject to a portfolio review by art faculty. Students who score a 4 or 5 on the AP test in other subject areas of the humanities and arts will receive credit in the relevant discipline. AP credit beyond one course (1/3 unit) in the Humanities and Arts may be counted toward other requirements such as free elective credit or particular majors and minors at WPI.

TRANSFER STUDENTS AND THE HUMANITIES AND ARTS REQUIREMENT

Students who transfer fewer than six Humanities and Arts courses from another institution must complete an inquiry seminar or practicum to complete the Humanities and Arts Requirement. Students who transfer six or more courses in Humanities and Arts will have the option of submitting a CDR form or engaging in additional work (or documentation of work) to earn an "A" on the CDR, in accordance with current transfer rules (see below).

All students may have the option of completing their Humanities and Arts Requirement while enrolled for 1 unit of coursework at an off-campus project center where one-third unit of the coursework shall include an inquiry seminar or practicum.

Transfer credit in the Humanities and Arts at WPI is granted on a course-for-course basis. All Transfer students entering WPI with *fewer than six courses or their equivalent of transfer credit in the Humanities and Arts* must complete work in the Humanities and Arts, including an Inquiry Seminar/Practicum to the extent that the overall Humanities and Arts credit totals two units.

No credit toward the Humanities and Arts Requirement is given for introductory-level foreign-language courses unless the entire program is in that foreign language. Usually only one transfer course in Freshman English can be applied toward the requirement. In all cases, the professor for the Inquiry Seminar/Practicum has the final decision on what courses are acceptable within the student's sequence leading up to the project. Up to one unit (i.e. three courses) of transferred work in the Humanities and Arts that is not credited toward the Humanities and Arts Requirement can be credited toward the fifteen-unit graduation requirement; such courses shall receive credit under the category of EL 1000.

If a Transfer student *has completed two units of acceptable college-level work in the Humanities and Arts prior to entering WPI*, a Completion of Degree Requirement form will be submitted by the Humanities and Arts Department Coordinator for Transfer Students at the request of the student. The grade for such a Humanities and Arts Requirement met by transfer credit is normally a grade of "CR". Students whose grades on transferred courses average A can engage in additional work or submit samples of their previous work and may be awarded an A for the Humanities and Arts Requirement. Alternately a transfer student may elect to undertake an Inquiry Seminar/Practicum in an effort to achieve an A grade. These evaluation options must be exercised prior to the Department's submission of the Completion of Degree Requirement form to the Registrar.

Decisions concerning credit toward the Humanities and Arts Requirement are made by the Humanities and Arts Coordinator for Transfer Students, Professor James Hanlan. He can be contacted in room 28 of Salisbury Laboratories, or at extension 5438, or email jphanlan@wpi.edu.

GUIDELINES FOR GRANTING TRANSFER CREDIT TO U.S. STUDENTS FOR FOREIGN LANGUAGE STUDY

A. Credit for study on the high school level:

1. Transfer credit of 1/3 unit is given for Advanced Placement with a score of 4 or 5.
2. Students with three or more years of foreign-language study in high school, but who have not taken the Advanced Placement examination in that language, may receive 1/3 unit credit for their high school language study upon satisfactory completion of two courses in the same language on the intermediate level or above. (Note: Courses in Chinese, German and Spanish in addition to those offered at WPI, as well as courses in other languages, are available at other colleges in the Consortium.)
3. In either case 1. or 2. above, in order to receive 1/3 unit credit, students must begin their WPI course sequence at the Elementary II level or above.

B. Credit for study at other colleges and universities:

1. Language study which is done at other universities and colleges prior to entering WPI, or done with the prior written permission of the student's Humanities and Arts Consultant (not the Department Head) as part of an agreed-upon Humanities and Arts sequence, transfers on a course-for-course basis.
2. Language study which is done at foreign universities, language institutes, cultural institutes, etc., prior to entering WPI, or done with the prior written permission of the student's Humanities and Arts Consultant (not the Department Head) as part of an agreed-upon Humanities and Arts sequence, is assessed by the Foreign Languages Consultant on the basis of matriculation papers and the level of work accomplished.

OTHER OPTIONS

INTERDISCIPLINARY STUDY AT THE AMERICAN ANTIQUARIAN SOCIETY

A unique opportunity for interdisciplinary work in the humanities and arts is offered by the American Studies Seminar sponsored each fall by the American Antiquarian Society. Organized in collaboration with Worcester's five undergraduate colleges and universities, this seminar focuses on topics that allow students to investigate the Society's rich holdings in early American history, literature, and culture. The Society's unparalleled collection of documents is a short walk from the campus. Information on application deadlines and academic credit toward the Humanities and Arts Requirement is available from the WPI Campus Representative to the American Antiquarian Society.

OFF-CAMPUS HUMANITIES AND ARTS OPTION

WPI offers the option to complete the Humanities and Arts Requirement during one term of study at several Project Centers. Normally, students complete the requirement through at least six courses or independent-study projects on campus. However, the "Off-Campus" option allows students to combine at least three courses on campus with one term studying the humanities and arts at a Project Center. Since this one-term project is equivalent to three courses, students may use it to complete the requirement.

Off-campus projects are available in Germany for the study of foreign languages and in London and Morocco for other fields. These off-campus programs have a flexible format. Students devote themselves to one term studying the history, literature, language or culture at the project site with a WPI faculty advisor. The program might combine a thematic seminar in an area of the faculty advisor's expertise with visits to museums, the theatre, musical performances, or cultural excursions.

Although themes or areas of emphasis vary from year to year, all off-campus Humanities and Arts activities culminate in a written report in an area of interest to the student.

To be eligible for this one-unit activity, students must have already completed three courses in humanities and arts before they leave campus. Students may apply to the off-campus program before they have taken all three courses. However, students may not participate in the program unless they successfully complete one unit of work in humanities and arts before the term of the project. In addition, students going to any Project Center must complete all of the forms required by the Interdisciplinary and Global Studies Division.

Requirements:

- Students must have completed at least three courses in the Humanities and Arts at WPI, or have earned equivalent course credit approved by the Humanities and Arts Department, before the term of the off-campus activity. The Department may allow students to count transfer or advanced placement credits toward the three course minimum;
- Students must be accepted into the off-campus Humanities and Arts program by the Humanities and Arts Department, and complete all forms required by the Interdisciplinary and Global Studies Division, in order to register for these projects.
- Students might be required by the faculty advisor to complete a PQP or attend required meetings before the off-campus project;
- Students must submit a written report or paper at the end of the project. Students also may be required to submit written updates at various times in the course of the project. In all cases, the faculty advisor at the project site will determine the precise form of the written requirements.
- Students may be required to give an oral presentation at the end of the project;
- Under normal circumstances, students must complete the project within one term in order to receive the full unit of credit;
- Only members of the Humanities and Arts faculty at WPI may advise off-campus Humanities and Arts projects.

OFF-CAMPUS RECOMMENDATIONS

All off-campus programs benefit from advance planning. Discuss the possibility of an off-campus activity with your academic advisor at the beginning of the freshman year. Consult with the WPI faculty who will advise these off-campus projects as early as possible, since they may be able to suggest useful courses or other background resources for the projects. Also keep in mind that three courses are the minimum required, but many students find it advantageous to take additional courses before going away.

The interdisciplinary London and Morocco programs are open to students with a background in areas of the humanities and arts besides foreign languages, including art history and architecture, drama/theatre, history, literature, music, philosophy, religion, or writing/rhetoric. After taking at least three courses in any of these areas on campus, you could then go to London to complete your project. Some students also have gone to London with this program to study beyond the Humanities and Arts Requirement for international and global studies, history, literature, music, theatre, or other areas.

WPI offers programs in the German language at Darmstadt. This program requires completion of foreign language courses through the level of intermediate II or above (2000-level or above) before going abroad. For students who have taken foreign language courses in high school, language placement exams are available during New Student Orientation. Some students with basic foreign language preparation have completed their arts projects in Germany. We welcome a creative approach to off-campus study.

More advanced students may participate in these off-campus programs by doing work toward a minor or major. A student who had already completed their Humanities and Arts Requirement on campus, for example, might be able to work in the humanities and arts on an Independent Study Project that could count toward a minor. Or a student at one of these sites could work on a Major Qualifying Project in fields such as Humanities and Arts, International and Global Studies, or Professional Writing.

The Humanities and Arts Department advertises upcoming project locations and application deadlines at the Global Opportunities Fair each September. Future project opportunities might include other foreign locations or projects that provide the context for an intensive study of humanistic themes associated with particular locales within the United States. Contact the Department of Humanities and Arts for more information.

THE SOCIAL SCIENCE REQUIREMENT

Social science deals with the behavior of individuals and groups as well as the functioning of the economic and political systems and institutions that shape and control our lives. As such, it offers a perspective that is essential for anyone desiring a well-rounded education.

Therefore, WPI, in common with other universities, requires some exposure to the social sciences for its graduates. In satisfying the two-course social science requirement, students are free to take courses in any of the traditional social sciences: economics, political science, sociology, and psychology. Courses with the following prefixes may be counted toward the social science requirement: ECON, ENV, GOV, PSY, SD, SOC, SS, STS. The social science courses offered at WPI are grouped into two broad categories. The first consists of core courses that introduce students to the social sciences and help them understand the scope and limits of social science approaches and how they might be related to the design of Interactive Qualifying Projects. The second, more advanced, set of courses looks in depth at particular issues and problems, providing students with a more detailed understanding of social science disciplines and their use in social problem solving and interactive projects.

To obtain maximum benefit from their study of social science, students should choose courses that will provide knowledge and skills relevant to their Interactive Qualifying Project. These courses should be taken prior to or concurrent with undertaking the IQP and should be selected, if possible, after the student has identified the general topic area in which his or her interactive project work will be carried out.

More information on the alternatives available and the factors that should be considered in choosing courses to satisfy the social science requirement are available on the Social Science and Policy Studies department website at https://www.wpi.edu/academics/study/programs/social-science-policy-studies/resources.

DEPARTMENT AND PROGRAM DESCRIPTIONS

Department and Program Descriptions . . . 29
Aerospace Engineering . . . 29
Minor in Aerospace Engineering . . . 32
Air Force Aerospace Studies . . . 32
Architectural Engineering . . . 33
Minor in Architectural Engineering (AREN) . . . 34
Bioinformatics and Computational Biology . . . 36
Minor in Bioinformatics and Computational Biology (BCB) 37
Biology and Biotechnology . . . 37
Minor in Biology . . . 38
Biomedical Engineering . . . 39
Business, Robert A. Foisie School of . . . 44
Business (BU) . . . 44
Management Engineering (MGE) . . . 47
Management Information Systems (MIS) . . . 47
Industrial Engineering . . . 48
Minor in Business . . . 50
Minor in Entrepreneurship . . . 50
Minor in Industrial Engineering . . . 50
Minor in Management Information Systems . . . 51
Minor in Social Entrepreneurship . . . 51
Chemical Engineering . . . 52
Chemistry and Biochemistry . . . 54
Minor in Biochemistry . . . 56
Minor in Chemistry . . . 56
Civil and Environmental Engineering . . . 57
Computer Science . . . 60
Minor in Computer Science . . . 63
Data Science . . . 65
Minor in Data Science . . . 66
Electrical and Computer Engineering . . . 70
Minor in Electrical and Computer Engineering . . . 73
Engineering Science Courses . . . 73
Environmental Engineering . . . 74
Fire Protection Engineering . . . 76
Humanities and Arts . . . 76
Professional Writing . . . 79
Humanities and Arts Minors . . . 80
American Studies . . . 80
Chinese Studies . . . 81
Drama/Theatre . . . 82
English . . . 82
Language (German or Spanish) . . . 82
History . . . 83
Media Arts . . . 83
Music . . . 83
Philosophy and Religion . . . 84
Writing and Rhetoric . . . 84
Interactive Media & Game Development . . . 84
Interactive Media & Game Development (Bachelor of Arts) 85
Interactive Media & Game Development Technology (Bachelor of Science) . . . 86
Minor in Interactive Media & Game Development . . . 87
Interdisciplinary and Global Studies . . . 87
Interdisciplinary Minors . . . 88
Minor in Global Public Health . . . 88
Minor in Nanoscience . . . 89
Minor in Sustainability Engineering . . . 89
International Development, Environment, and Sustainability (IDEaS) (Bachelor of Arts Degree) . . . 90
Major in Environmental and Sustainability Studies . . . 91
Minor in Environmental and Sustainability Studies . . . 91
Minor in Science and Engineering for Development (DEV) . 92
International and Global Studies . . . 92
Minor in International and Global Studies . . . 92
Liberal Arts and Engineering (Bachelor of Arts Degree) . . . 95
Mathematical Sciences . . . 97
Minor in Statistics . . . 101
Minor in Mathematics . . . 102
Mechanical Engineering . . . 102
Minor in Mechanical Engineering . . . 106
Minor in Manufacturing Engineering . . . 106
Materials Engineering . . . 107
Minor in Materials . . . 107
Military Science . . . 108
Physical Education, Recreation, and Athletics . . . 109
Physics . . . 110
Minor in Physics . . . 113
Minor in Astrophysics . . . 114
Pre-Professional Programs . . . 114
Five-Year Dual Bachelor/M.S. in Management (MSMG) . . 114
Pre-Health Programs . . . 115
Pre-Law Programs . . . 115
Teacher Preparation Program . . . 115
Robotics Engineering . . . 116
Minor in Robotics Engineering . . . 117
Social Science and Policy Studies . . . 117
Economic Science Program . . . 118
Psychological Science Program . . . 119
Society, Technology, and Policy Program . . . 120
Minor in Law and Technology . . . 121
Minors in Social Science . . . 121

SECTION 2

AEROSPACE ENGINEERING

N.A. GATSONIS, DIRECTOR
PROFESSORS: M. Demetriou, N. A. Gatsonis
ASSOCIATE PROFESSORS: J. Blandino, R. Cowlagi, D. Olinger, M. Richman
ASSISTANT PROFESSORS: J. Jayachandran, N. Karanjgaokar
ASSISTANT TEACHING PROFESSOR: Z. Taillefer

MISSION STATEMENT
The Aerospace Engineering Program seeks to impart to our students strong technical competence in fundamental engineering principles along with specialized competence in aeronautical and astronautical engineering topics. The Program also seeks to foster a student's creative talents with the goal of developing a personal high standard of excellence and professionalism. Finally, the Aerospace Engineering Program seeks to provide to our students an appreciation of the role of the aerospace engineer in society.

PROGRAM EDUCATIONAL OBJECTIVES
The graduates of the Aerospace Engineering Program:

1. Will be successful professionals in aerospace and related engineering areas employed by industry or government.
2. Will be recipients of graduate degrees in aerospace and related engineering areas or in other professional areas.
3. Will become leaders in industry or government due to their mastery of technical concepts, broad preparation in the effective uses of technology, communication, and teamwork, and due to their appreciation of the importance of professional responsibilities and impact of technology on society.

STUDENT OUTCOMES
Graduating students should demonstrate that they attain the following:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factor.
3. an ability to communicate effectively with a range of audiences.
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.
8. knowledge covering one area emphasized – aeronautical engineering or astronautical engineering – and, in addition, knowledge of some topics from the area not emphasized.
9. major engineering design competence that incorporates appropriate engineering standards and multiple constraints, is based on the knowledge and skills acquired in earlier course work, and includes integration of aeronautical or astronautical topics

Program Distribution Requirements for the Aerospace Engineering Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see WPI Degree Requirements) students wishing to receive a Bachelor degree in "Aerospace Engineering", must satisfy additional distribution requirements. These requirements apply to 10 units of study in the areas of mathematics, basic sciences, aerospace engineering science and design.

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Basic Sciences (Notes 1,2,3,4)	10/3
2. Engineering Topics (Notes 5,7)	16/3
3. Major Engineering Design Experience (including MQP) (Note 6)	4/3

NOTES:

1. Must include a minimum of 6/3 units of mathematics (prefix MA) with topics in: differential, integral, vector, multivariable calculus, differential equations, and linear algebra.
2. Must include a minimum of 2/3 units in physics (prefix PH) with topics in: mechanics, electricity and magnetism.
3. Must include 1/3 units in space environments (fulfilled by PH/AE 2550 Atmospheric and Space Environments as a Math and Basic Science course or other equivalent course with approval of the AE Program Undergraduate Committee)
4. Must include 1/3 unit in chemistry (prefix CH).
5. Must include 16/3 units of Engineering Topics, distributed as follows:
   a. 14/3 units of Aeronautical Engineering
      i. 2/3 units of Aerodynamics, with topics in: compressible fluid dynamics, subsonic and supersonic aerodynamics.
      ii. 2/3 units of Aerospace Materials, with topics in: introductory materials science, and advanced materials.
      iii. 3/3 units of Structures, with topics in: stress analysis, aerospace structures, and structural dynamics.
      iv. 3/3 units of Propulsion, with topics in: thermodynamics, incompressible fluid dynamics, and air breathing propulsion.
      v. 3/3 units of Flight Mechanics, and Stability and Control, with topics in: dynamics, control theory, and aircraft dynamics and control.
      vi. 1/3 units of Experimentation.
   b. 2/3 units in Astronautical Engineering
      i. 1/3 units of Orbital Mechanics (fulfilled by AE 2713 Astronautics).
      ii. 1/3 units of Telecommunications (fulfilled by AE 4733 Guidance, Navigation and Communication).
6. Must include 4/3 Units of Major Engineering Design Experience devising an aerospace system, component, or process to meet desired needs that incorporates appropriate engineering standards and multiple constraints, is based on the knowledge and skills acquired in earlier course work, and includes integration of aeronautical or astronautical topics (fulfilled by 1/3 Unit in AE 4770 Aircraft Design and 3/3 Units in MQP).

AEROSPACE ENGINEERING PROGRAM CHART
Course Recommendation

12/3 UNITS OF GENERAL EDUCATION ACTIVITIES			
HUA 6/3 Units	See WPI Requirements and Note 1	**Interactive Qualifying Project** 3/3 Units	See WPI Requirements
Social Science 2/3 Units	See WPI Requirements and Note 1	**Physical Education** 1/3 Unit	See WPI Requirements

3/3 UNITS OF FREE ELECTIVE
See WPI Requirements and Note 1

Note 1: First year Great Problems Seminar (GPS) courses can only be used to fulfill the HUA, SSPS, or the Free Elective requirement

10/3 UNITS OF MATHEMATICS AND BASIC SCIENCE (Note 2)			
Mathematics 6/3 Units	4/3 Units in Calculus (MA 1021, MA 1022, MA 1023, MA 1024) 1/3 Units in Differential Equations (MA 2051) 1/3 Units in Linear Algebra (MA 2071)	**Physics** 2/3 Units	1/3 Units in Mechanics (PH 1110 or PH 1111 or PH 2201) 1/3 Units Electricity & Magnetism (PH 1120 or PH 1121)
(Chemistry 1/3 Unit	CH 1010 Chemistry I or CH 1020 Chemistry II	**Space Environments** 1/3 Unit	PH/AE 2550 Atmospheric and Space Environments

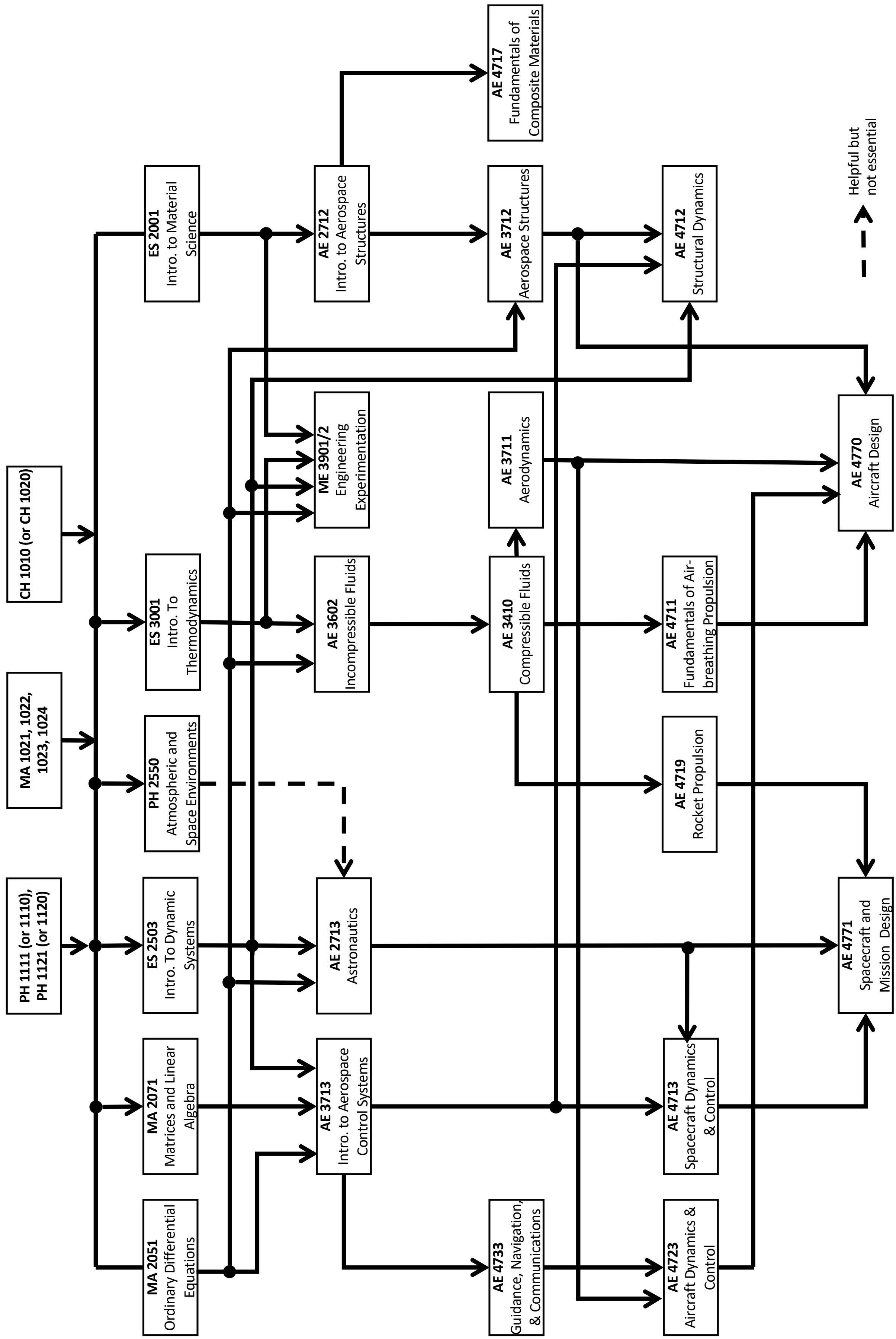
20/3 UNITS OF ENGINEERING TOPICS (Note 2)	
14/3 Units of AERONAUTICAL ENGINEERING	
Aerodynamics 2/3 Units	AE 3410 Compressible Fluid Dynamics AE 3711 Aerodynamics
Aerospace Materials 2/3 Units	ES 2001 Intro to Materials Science AE 4717 Fundamentals of Composite Materials
Structures 3/3 Units	AE 2712 Intro to Aerospace Structures AE 3712 Aerospace Structures AE 4712 Structural Dynamics
Propulsion 3/3 Units	ES 3001 Intro to Thermodynamics AE 3602 Incompressible Fluids AE 4711 Fundamentals of Air Breathing Propulsion
Flight Mechanics, and Stability and Control 3/3 Units	ES 2503 Intro to Dynamic Systems AE 3713 Intro to Aerospace Control Systems AE 4723 Aircraft Dynamics & Control
Experimentation 1/3 Unit	ME 3901or ME 3902 Engineering Experimentation
2/3 Units of ASTRONAUTICAL ENGINEERING	
Orbital Mechanics 1/3 Unit	AE 2713 Astronautics
Telecommunications 1/3 Unit	AE 4733 Guidance, Navigation and Communications
4/3 UNITS OF MAJOR ENGINEERING DESIGN EXPERIENCE	
1/3 Unit	AE 4770 Aircraft Design
3/3 Units	Major Qualifying Project in Aerospace Engineering

or

20/3 UNITS OF ENGINEERING TOPICS (Note 2)	
14/3 Units of ASTRONAUTICAL ENGINEERING	
Orbital Mechanics 2/3 Unit	ES 2503 Intro to Dynamic Systems AE 2713 Astronautics
Attitude Determination and Control 2/3 Units	AE 3713 Intro to Aerospace Control Systems AE 4713 Spacecraft Dynamics & Control
Telecommunications 1/3 Unit	AE 4733 Guidance, Navigation and Communications
Space Structures 4/3 Units	ES 2001 Intro to Materials Science AE 2712 Intro to Aerospace Structures AE 3712 Aerospace Structures AE 4712 Structural Dynamics
Rocket Propulsion 4/3 Units	ES 3001 Intro to Thermodynamics AE 3602 Incompressible Fluids AE 3410 Compressible Fluid Dynamics AE 4719 Rocket Propulsion
Experimentation 1/3 Unit	ME 3901or ME 3902 Engineering Experimentation
2/3 Units of AERONAUTICAL ENGINEERING	
Aerodynamics 1/3 Unit	AE 3711 Aerodynamics
Flight Mechanics, and Stability and Control 1/3 Unit	AE 4723 Aircraft Dynamics and Control
4/3 UNITS OF MAJOR ENGINEERING DESIGN EXPERIENCE	
1/3 Unit	AE 4771 Spacecraft and Mission Design
3/3 Units	Major Qualifying Project in Aerospace Engineering

Note 2: The courses in the above chart can be replaced by other equivalent courses, with the approval of the AE Program.

AEROSPACE ENGINEERING MAJOR COURSE FLOW CHART



or

5. Must include 16/3 units of Engineering Topics, distributed as follows:
   a. 14/3 units of Astronautical Engineering
      i. 2/3 units of Orbital Mechanics, with topics in: dynamics and space flight mechanics.
      ii. 2/3 units of Attitude Determination and Control, with topics in: control theory, and spacecraft dynamics and controls.
      iii. 1/3 units of Telecommunications, with topics in: guidance, navigation and communication.
      iv. 4/3 units of Space Structures, with topics in: introductory material science, stress analysis, aerospace structures, and structural dynamics.
      v. 4/3 units of Rocket Propulsion, with topics in: thermodynamics, incompressible fluid dynamics, compressible fluid dynamics, and rocket propulsion.
      vi.1/3 units of Experimentation.
   b. 2/3 units in Aeronautical Engineering
      i. 1/3 units of Aerodynamics (fulfilled by AE 3711 Aerodynamics).
      ii. 1/3 units of Flight Mechanics, and Stability and Control (fulfilled by AE 4723 Aircraft Dynamics and Control).
6. Must include 4/3 units of Major Engineering Design experience devising an aerospace system, component, or process to meet desired needs that incorporates appropriate engineering standards and multiple constraints, is based on the knowledge and skills acquired in earlier course work, and includes integration of aeronautical or astronautical topics (fulfilled by 1/3 Unit in 4771 Spacecraft and Mission Design and 3/3 Units in the MQP).
7. Great Problem Seminar (GPS) courses can only be used to fulfill the HUA, SSPS or the Free Elective requirement.

MAJOR QUALIFYING PROJECTS

The Aerospace Engineering Program provides opportunities, resources and organization for Major Qualifying Projects (MQPs). The MQPs involve the design of an aerospace system, component, or process to meet desired needs that incorporates appropriate engineering standards and multiple constraints, is based on the knowledge and skills acquired in earlier course work, and include the integration of aeronautical and/or astronautical engineering topics. MQPs are conducted in a dedicated lab or in one of the research laboratories of the Aerospace Engineering Program and serve as a vehicle for integration of undergraduate studies with current research activities. Some MQPs are also conducted in collaboration with industry or government research centers. All students present their MQP in a conference held at WPI on Project Presentation Day. Students are also encouraged and often supported to participate in student and professional conferences, as well as national design competitions. (https://www.wpi.edu/academics/departments/aerospace-engineering)

MINOR IN AEROSPACE ENGINEERING

For students who are not AE majors and are interested in broadening their exposure to, and understanding of, aerospace engineering, the Aerospace Engineering Program offers a Minor in Aerospace Engineering.

Successful candidates for the Minor in AE must meet the following requirements:

1. Complete two units of work from courses with the prefix “AE” as outlined in the table below.
2. Of the work in (1), at least 2/3 unit must be in 4000-level “AE” courses.

2 Units in AEROSPACE ENGINEERING		
Aerodynamics and Propulsion	AE 2713	Astronautics
	AE 3410	Compressible Fluid Dynamics
	AE 3711	Aerodynamics
	AE 4711	Fundamentals of Air-Breathing Propulsion
	AE 4719	Rocket Propulsion
Aerospace Materials and Structures	AE 3712	Aerospace Structures
	AE 4712	Structural Dynamics
	AE 4717	Fundamentals of Composite Materials
Aerospace vehicle Dynamics, Stability and Control	AE 4723	Aircraft Dynamics and Control
	AE 4713	Spacecraft Dynamics and Control
	AE 4733	Guidance, Navigation and Communications
Major Aerospace Design Experience	AE 4770	Aircraft Design
	AE 4771	Spacecraft and Mission Design

Students seeking a Minor in AE should complete the Application for the Minor in AE and submit it to the AE Program Office as early in the program of study as possible. The Application for Minor in AE is available in the AE Program Office and the AE website. The AE Program Undergraduate Committee Chair will be responsible for review and approval of all Minor in AE requests. WPI policy requires that no more than one unit of course work be double counted toward other degree requirements.

THE COMBINED BACHELOR'S/MASTERS PROGRAM

Students are encouraged to consider the BS/MS program in Aerospace Engineering. Details are found in the WPI graduate catalog.

AIR FORCE AEROSPACE STUDIES

LT COL J. SKILES III, DEPARTMENT HEAD
PROFESSOR: Lt Col J. Skiles III
ASSISTANT PROFESSOR: Capt. N. Evans

MISSION

The mission of AFROTC is to develop leaders of character for tomorrow's Air Force, whose mission is to fly, fight, and win in air, space, and cyberspace. Successful graduates of the program receive a commission as a Second Lieutenant in the United States Air Force.

EDUCATIONAL OBJECTIVES:

Students who successfully complete the AFROTC program will develop:

1. An understanding of the fundamental concepts and principles of Air and Space.
2. A basic understanding of associated professional knowledge.
3. A strong sense of personal integrity, honor, and individual responsibility.
4. An appreciation of the requirements for national security.

AIR FORCE ROTC PROGRAMS

There are two traditional routes to an Air Force commission through Air Force ROTC. Entering students may enroll in the Air Force Four-Year Program. Students with at least three academic years remaining in college may apply for the Accelerated Program.

FOUR- OR FIVE-YEAR PROGRAM

The preferred program is the traditional Four-Year Program. To enroll, simply register for Air Force Aerospace Studies in the fall term of the freshman year in the same manner as other college courses. There is NO MILITARY OBLIGATION for the first two years of Air Force ROTC unless you have an Air Force ROTC scholarship.

The first two years are known as the General Military Course (GMC). Classes meet one hour per week and are required for freshmen and sophomores.

Individuals who successfully complete the GMC compete nationwide for entry into the Professional Officers Course (POC). POC classes meet three hours per week and are required for all juniors and seniors. Officer Candidates enrolled in the POC and on scholarship receive a nontaxable subsistence allowance of up to $500 each month.

Qualified Officer candidates will attend the Air Force ROTC field-training program for four weeks, usually between their sophomore and junior years.

ACCELERATED PROGRAM

For students who do not enroll in Air Force ROTC during their first year in college, it is possible to condense the two years of GMC membership into a single year, as long as the student has three more years of college left.

OTHER ASPECTS OF THE AFROTC PROGRAM

Leadership Laboratory:

Air Force ROTC officer candidates participate in a Leadership Laboratory (LLAB) where the leadership skills and management theories acquired in the classroom are put into practice. The LLAB meets once each week for approximately two hours.

This formal military training is largely planned and directed by the officer candidates. The freshmen and sophomores are involved in such initial leadership experiences as problem solving, dynamic leadership, team building, Air Force customs and courtesies, drill movements, Air Force educational benefits, Air Force career opportunities, and preparation for field training. The juniors and seniors are involved in more advanced leadership experiences as they become responsible for the planning and organizing of wing activities, including conducting the Leadership Laboratory itself.

Field Training:

The summer program is designed to develop military leadership, discipline, and evaluate performance. At the same time, the Air Force can evaluate each student's potential as an officer. Field training includes: expeditionary operations, Air Force professional development, marksmanship training, physical fitness, and survival training.

Base Visits:

Air Force ROTC officer candidates may have the opportunity to visit Air Force bases for firsthand observation of the operating Air Force.

Additional Information:

In addition to formal activities, the cadet wing plans and organizes a full schedule of social events throughout the academic year. These include a Dining-In, Military Ball, a Field Day, and intramural sports activities. Professional Development Training Programs, such as Advanced Cyber Education, internships with the National Reconnaissance Office, combative training, and global cultural language and immersion training may also be available to selected volunteer officer candidates during the summer. Students may also participate in Arnold Air Society, Drill Team, and Civil Air Patrol, among other activities.

ARCHITECTURAL ENGINEERING

DIRECTOR: S. VAN DESSEL (AREN)

ASSOCIATED FACULTY: L. Albano (CEE), T. El-Korchi (CEE), M. Farzinmoghadam (AREN), S. Liu (AREN)

MISSION STATEMENT

Architectural Engineering is a discipline that focuses on the planning, design, construction and operation of buildings and, particularly, on their parts that support the functioning of the inner space and the undertaking of human activities, including environmental protection, comfort, well-being, sustainability and security. One of the major focuses of the architectural engineering program at WPI is the use of energy in buildings, and this is addressed through courses and projects that incorporate engineering science and design fundamentals that relate to those building parts, e.g., envelope, heating and air conditioning, plumbing and electrical systems, which impact the consumption of energy and natural resources. The program seeks to impart to students strong technical competence in fundamental engineering principles as they are applied to a sustainable built environment. The program, in addition, seeks to foster a student's creative undertaking and his/her development of high standards of professionalism. The project approach at WPI offers students a unique opportunity to explore the humanistic, technological, societal, economic, legal, and environmental issues surrounding architectural engineering problems. The architectural engineering degree prepares students for careers in the private and public sectors, architectural and engineering consulting, real estate and construction firms, and advanced graduate studies.

PROGRAM EDUCATIONAL OBJECTIVES

The objective of the undergraduate program in Architectural Engineering is to prepare graduates for successful careers in the Architectural Engineering profession. A few years after graduation WPI Architectural Engineering graduates are expected to have the ability to:

1. Attain registration as Professional Engineers,
2. Earn a graduate degree in Architectural Engineering or a related discipline,
3. Enhance their skills through continued education,
4. Serve their profession through engagement with professional societies,
5. Demonstrate commitment to sustainable design principles within their professional work

STUDENT OUTCOMES

The Student Outcomes for the Bachelor degree in Architectural Engineering are that all graduates will attain:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies
8. the design level in one of the four architectural engineering areas, the application level in a second area, and the comprehension level in the remaining two areas.

Program Distribution Requirements for the Architectural Engineering Major

The program is designed according to the ABET criteria for Architectural Engineering accreditation. The four basic architectural engineering curriculum areas are building structures, building mechanical systems, building electrical systems and construction/construction management. The normal period of residency at WPI is 16 terms. In addition to WPI requirements applicable to all students (see WPI Degree requirements), students wishing to receive a Bachelor degree in "Architectural Engineering" must satisfy the following distribution requirements:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics, Basic Science, and Supplemental Science (Note 1)	4
2. Architectural Engineering Science and Design (Notes 2, 3, 4)	7

NOTES:

1. Must include a minimum of 10/3 units of a combination of Mathematics and Basic Sciences. Mathematics must include differential and integral calculus, differential equations, statistics, and matrices and linear algebra. Science must include 2/3 unit in calculus-based physics (PH 1110 or PH 1111 and PH 1120 or PH 1121), 1/3 unit in chemistry, 1/3 unit in thermodynamics (can be fulfilled by PH 2101 or other approved equivalent course such as ES 3001), and 1/3 unit in fluid mechanics (can be fulfilled by ES 3004).
2. Must include 7 units of Architectural Engineering Science and Design in the different areas of architectural engineering, distributed as follows or with approved equivalents:
   a) 2/3 units of architectural engineering complements, including introduction to architectural engineering (AREN 2023) and topics related to the history and theory of architecture (AR 2114).
   b) 2/3 units in construction/construction management including project evaluation (CE 3025) or Engineering Economics (OIE 2850), and either legal aspects of professional practice (CE 3022) or project management (CE 3020).
   c) 5/3 units in building mechanical systems including Building Physics (AREN 3024), Principles of HVAC design for buildings (AREN 3003), Advanced HVAC system design (AREN 3006), and two integrated architectural design studios: Architectural Design IV - Building energy simulation (AREN 3020), and Architectural Design V - Building Envelop Design (AREN 3022).
   d) 2/3 units in building electrical systems with topics in building electrical systems (AREN 2025) and Architectural Design II - Light and Lighting Systems (AREN 2004)
   e) 5/3 units in building structural systems including Analytical Mechanics 1 and 2 (CE 2000 and CE 2001), Introduction to Analysis and Design (CE 2002), and two design level structural engineering courses (such as CE 3006, CE 3008, CE 3010, or CE 3044)
   f) 2/3 Units in general architectural design including Architectural Design I (AREN 2002), and Architectural Design III (AREN 3002).
   g) Must include the Capstone Design activity (1 Unit) through the MQP that achieves design proficiency in either the structural or mechanical area.
3. Must include 1/3 unit in Experimentation (fulfilled by AREN 3003, AREN 3020, ME 3901, CE 3026 or approved equivalent).
4. Great Problem Seminar (GPS) courses can only be used to fulfill the HUA, SSPS, or the Free Elective requirements.

For more information please consult the website for this major at https://www.wpi.edu/academics/departments/architectural-engineering.

MINOR IN ARCHITECTURAL ENGINEERING (AREN)

For students who are not AREN majors and are interested in broadening their exposure to and understanding of architectural engineering, the Architectural Engineering Program offers a Minor in Architectural Engineering.

Successful candidates for the Minor in AREN must complete two units of work from courses with the pre fix "AREN" as outlined in the table below.

2 Units in Architectural Engineering

Must include:

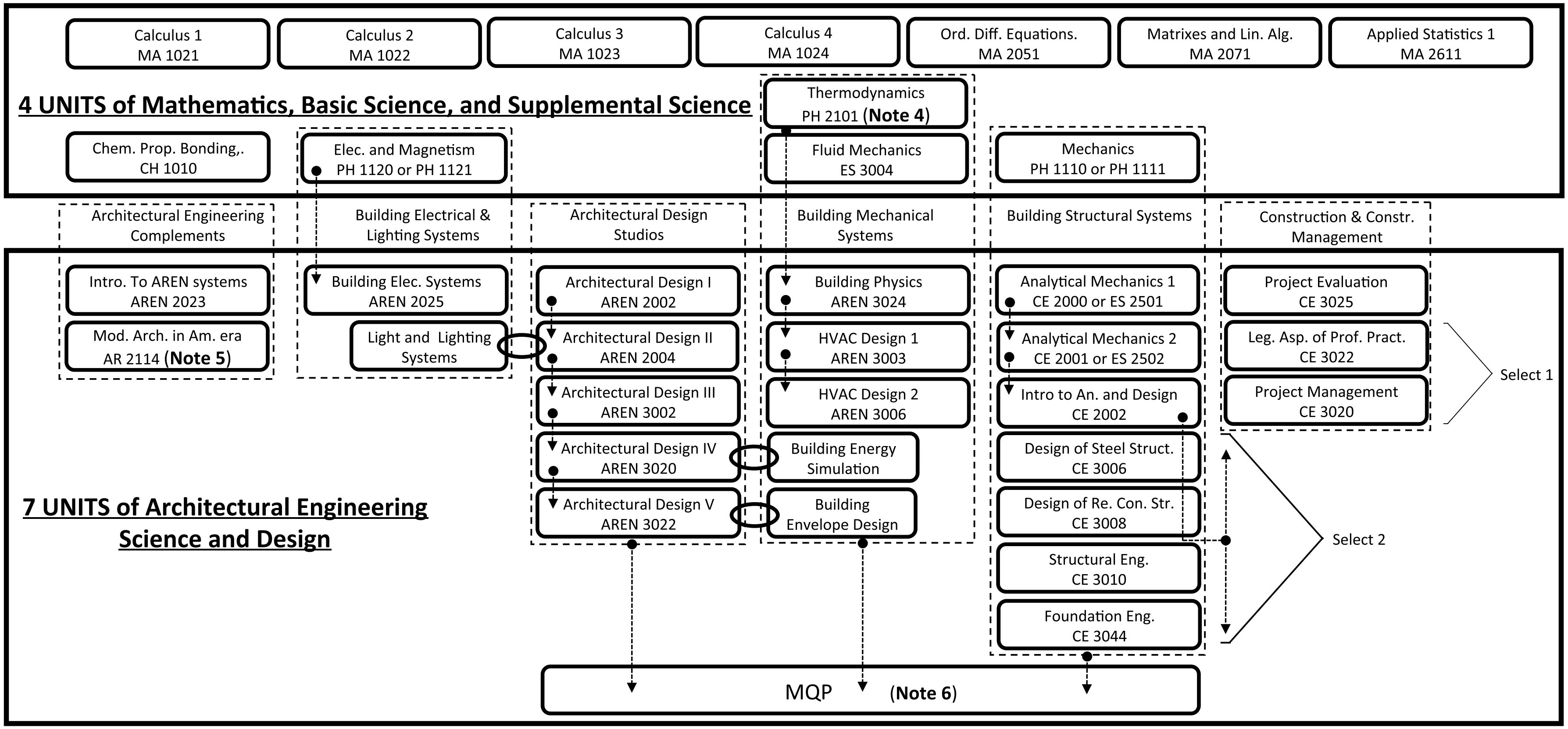
AREN 2002	Architectural Design I
AREN 2023	Introduction to Architectural Engineering Systems
AREN 3003	Principles of HVAC Design for Buildings

Elective courses (select three)

AREN 2025	Building Electrical Systems
AREN 2004	Architectural Design II – Light and lighting systems
AREN 3002	Architectural Design III
AREN 3006	Advanced HVAC System Design
AREN 3024	Building Physics
AREN 3020	Architectural Design IV – Building Energy Simulation
AREN 3022	Architectural Design V – Building Envelope Design

ARCHITECTURAL ENGINEERING PROGRAM CHART (NOTE 1, 2)

This chart summarizes course recommendations (**Note 3**)



4 UNITS additional Degree Requirements

Humanities and Arts	6/3 Units
Social Sciences	2/3 Units
IQP	3/3 Units
Physical Education	1/3 Units
Free Electives	(Note 7)

Note 1: The courses in this Architectural Engineering Program chart can be replaced by approved equivalents.

Note 2: Must include 1/3 unit in Experimentation (fulfilled by AREN 3003, AREN 3025, or approved equivalent).

Note 3: Arrows indicate recommended order of topics.

Note 4: Can be fulfilled by PH 2101 or other approved equivalent course such as ES 3001.

Note 5: This course can also help fulfill the Humanities and Arts requirement.

Note 6: Must include the Capstone Design activity that achieves design proficiency in either the structural or mechanical area.

Note 7: The minimum academic credit required for the Bachelor degree is 15 units. Credit accumulated beyond the published distribution requirements shall be accomplished by the addition of "free elective" work.

Students seeking a Minor in AREN should complete the Application for the Minor in AREN and submit it to the Director of AREN Program as early in the program of study as possible. The Application for Minor in AREN is available in the Civil and Environmental Engineering Office. The Director of the AREN Program will be responsible for the review and approval of all Minor in AREN requests. WPI policy requires that no more than one unit of course work be double counted toward other degree requirements.

BIOINFORMATICS AND COMPUTATIONAL BIOLOGY

DIRECTOR: D. KORKIN (CS)
ASSOCIATE DIRECTOR: E. RYDER (BB)
PROGRAM COMMITTEE: L. Harrison (CS), X. Kong (CS), A. Manning (BB), S. Olsen (MA), R. Paffenroth (MA), R. Rao (BB), C. Ruiz (CS), B. Servatius (MA), S. Shell (BB), L. Vidali (BB), Z. Wu (MA)
AFFILIATED FACULTY: E. Agu (CS), A. Arnold (MA), J. Duffy (BB), M. Y. Eltabakh (CS), K. Lee (BME), W.J. Martin (MA), A. Mattson (CBC), E.A. Rundensteiner (CS), E. Solovey (CS), J. Srinivasan (BB), D. Tang (MA), S. Walcott (MA), M. Wu (MA), A. Yousefi (CS), J. Zou (MA)

MISSION STATEMENT

With the advent of large amounts of biological data stemming from research efforts such as the Human Genome Project, there is a great need for professionals who can work at the interface of biology, computer science, and mathematics to address important problems involving complex biological systems. Graduates of this interdisciplinary program will be well versed in all three disciplines, typically specializing in one of them. Many opportunities for interdisciplinary research projects are available, both on the WPI campus, and through relationships with faculty at the University of Massachusetts Medical School. Graduates will be well-prepared for graduate study or for professional careers in industry.

PROGRAM OUTCOMES

Students graduating with a Bachelor of Science degree in Bioinformatics and Computational Biology:

- Have mastered foundational studies in biology, mathematics, and computer science
- Have mastered advanced principles and techniques in at least one of the three disciplines
- Can apply computational and mathematical knowledge to the solution of biological problems
- Can communicate effectively across disciplines both verbally and in writing
- Can locate, read, and interpret primary literature in bioinformatics and computational biology
- Can formulate hypotheses or models, design experiments to test these hypotheses, and interpret experimental data
- Can function effectively as members of an interdisciplinary team
- Adhere to accepted standards of ethical and professional behavior
- Will be life-long independent learners

Program Distribution Requirements for the Bioinformatics and Computational Biology Major

The distribution requirements for the BS degree in Bioinformatics consists of core courses in Biology, Chemistry, Mathematics, and Computer Science, several interdisciplinary courses, and a set of advanced courses primarily focused on one of three disciplines: Computer Science, Biology/Biochemistry, or Mathematics.

REQUIREMENTS	MINIMUM UNITS
1. Mathematics (Note 1)	5/3
2. Computer Science (Note 2)	4/3
3. Biology (Note 3)	5/3
4. Chemistry (Note 4)	4/3
5. Bioinformatics and Computational Biology (Note 5)	3/3
6. Social Implications (Note 6)	1/3
7. Advanced disciplinary courses (Note 7)	6/3
8. MQP	3/3

NOTES:

1. Mathematics must include 3/3 unit of differential and integral calculus and statistics. The additional 2/3 unit must be chosen from linear algebra, statistics, probability, calculus, and differential equations.
2. Computer Science must include 2/3 unit of introductory programming and 2/3 unit of discrete math and algorithms.
3. Biology must include cell biology, genetics, molecular biology, and 1/3 unit BB 2000-level laboratory.
4. Chemistry must include 2/3 unit of general chemistry and 2/3 unit of organic chemistry.
5. Chosen from BCB interdisciplinary courses.
6. Chosen from CS 3043 or PY 2713.
7. Chosen from advanced courses in MA, CS, BB, or CH listed below. At least one unit must be within one area (MA, CS, or BB/CH). At least one unit must be at the 4000 level (may be in different areas).

Advanced courses in MA:

MA 2431	Mathematical Modeling with Ordinary Differential Equations
MA 2621	Probability for Applications
MA 2631	Probability
MA 3627	Introduction to the Design and Analysis of Experiments
MA 3631	Mathematical Statistics
MA 4214	Survival Models
MA 4473	Partial Differential Equations
MA 4631	Probability and Mathematical Statistics I
MA 4632	Probability and Mathematical Statistics II

Advanced courses in CS:

CS 3733	Software Engineering
CS 3431	Database Systems I
CS 4120	Analysis of Algorithms
CS 4341	Introduction to Artificial Intelligence
CS 4432	Database Systems II
CS 4445	Data Mining and Knowledge Discovery in Databases

Advanced courses in BB/CH:

Any BB 3000/4000 level course or CH 4000 level Biochemistry course. Particularly relevant BB/CH courses:

BB 3140	Evolution: Pattern and Process
BB/CH 4190	Regulation of Gene Expression
CH 4110	Protein Structure and Function
CH 4120	Lipids and Biomembrane Functions
CH 4130	Nucleic Acids and Bioinformation

MINOR IN BIOINFORMATICS AND COMPUTATIONAL BIOLOGY (BCB)

Students pursing the Bioinformatics and Computational Biology minor need to acquire some familiarity with the three fields that form the basis of this interdisciplinary area: biology, mathematics, and computer science. They should also take at least one interdisciplinary course that uses quantitative methods to pose and answer biological problems. Students should be careful to choose their mathematics, computer science, and biology courses to prepare themselves for whichever capstone BCB course they plan to take.

REQUIREMENTS

1. 5/3 units in BB, MA, CS, and BCB, chosen from the course lists below, with at least 1/3 unit in each of BB, CS, and MA, and no more than 2/3 unit from any of these three areas. No more than 1 course at the 1000 level may be included from any one department.
2. 1/3 unit capstone: any BCB 4000 level class.

MA courses

MA 2610	Statistics for the Life Sciences or MA 2611 Applied Statistics I
MA 2612	Applied Statistics II
MA 2621	Probability for Applications
MA 2051	Ordinary Differential Equations
MA 2631	Probability

Any course from the Advanced courses in MA list for the BCB major

CS courses

CS 1004	Intro to Programming for Non-Majors
CS 1101	Intro to Programming or CS 1102 Accelerated intro to Programming
CS 2102	Object Oriented Design or CS 2103 Accelerated Object Oriented Design
CS 2223	Algorithms

Any course from the Advanced courses in CS list for the BCB major

BB courses

BB 1035	Biotechnology
BB 1045	Biodiversity
BB 1025	Human Biology
BB 2920	Genetics
BB 2950	Molecular Biology
BB 2550	Cell Biology
BB 2002	Microbiology
BB 2040	Ecology

Any course from the Advanced courses in BB/CH list for the BCB major

BCB Interdisciplinary courses

BCB 3010	Simulation in Biology
BCB 4001	Bioinformatics
BCB 4002	Biovisualization
BCB 4003	Biological and Biomedical Database Mining
BCB 4004	Statistical Methods in Genetics and Bioinformatics

BIOLOGY AND BIOTECHNOLOGY

J. DUFFY, HEAD; J. RULFS, ASSOCIATE HEAD

PROFESSORS: D. S. Adams, J. King, K. Oates, R. Rao, P. J. Weathers
ASSOCIATE PROFESSORS: T. Dominko, J. Duffy, L. Mathews, J. Rulfs, E. Ryder, J. Srinivasan, L. Vidali
ASSOCIATE TEACHING PROFESSORS: M. Buckholt, L. Roberts, J. Whitefleet-Smith
ASSISTANT PROFESSORS: N. Farny, A. Manning, I. Nechipurenko, S. Shell
PROFESSOR OF PRACTICE: F. Brownewell
ASSISTANT RESEARCH PROFESSOR: B. Nephew
AFFILIATE FACULTY: M. Bakermans
EMERITUS PROFESSORS: R. Cheetham, T. C. Crusberg

MISSION STATEMENT

The Department of Biology and Biotechnology will make scholarly scientific and technological advances that will address the changing needs of society. We will prepare well educated scientists able to approach problems with creativity and flexibility. A key element in this preparation is active participation in the process of scientific inquiry.

EDUCATIONAL PROGRAM

Our educational program is founded in five unifying concepts.

1. All living things evolve through processes such as genetic drift and natural selection that act on heritable genetic variation.
2. Biological systems obey the principles of chemistry and physics.
3. Simple biological units can assemble into more complex systems with emergent properties.
4. Biological systems function by the actions of complex regulatory systems.
5. Scientific knowledge follows a process of observation and hypothesis testing.

An integrated and functional understanding of these concepts provides the foundation for biotechnology, *the technological application of biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use.* (United Nations Convention on Biological Diversity)

In the Biology & Biotechnology curriculum, these concepts are exemplified and integrated across three major divisions of biology:

- Cellular and molecular biology
- Biology of the organism
- Organisms in their environment

PROGRAM LEARNING OUTCOMES

The program's learning outcomes are designed to support life-long learning in the discipline. Toward that end, graduates of WPI with a Bachelor of Science degree in Biology & Biotechnology

- will know and understand the five unifying themes and can provide and explain examples of each from each of the three divisions of biology.

- can demonstrate mastery of a range of quantitative and procedural skills applicable to research and practice in biology & biotechnology.
- are able to generate hypotheses, design approaches to test them, and interpret data to reach valid conclusions.
- can find, read and critically evaluate the scientific literature.
- can describe the broader scientific or societal context of their work or that of others.
- demonstrate oral and written communication skills relevant to the discipline.
- can function effectively in a collaborative scientific environment.
- understand and can adhere to accepted standards of intellectual honesty in formulating, conducting and presenting their work.

Program Distribution Requirements for the Biology and Biotechnology Major

REQUIREMENTS	MINIMUM UNITS
1. Mathematical Sciences, Physics, Computer Science, Engineering (Note 1)	5/3
2. Chemistry	5/3
3. Biology & Biotechnology (Note 2)	10/3
4. Laboratory experience (Note 3)	4/3
5. Related courses (Note 4)	3/3
6. MQP	1

NOTES:

1. BB 3010 and BB 4801 may count toward this requirement.
2. Biology and Biotechnology coursework must include 2/3 units at the 1000 level, 4/3 units at the 2000 level, and 4/3 units at the 3000/4000 level, of which at least 1/3 unit must be a BB 4900 course. BB 1000, BB 1001, BB 1002 and BB/BCB 1003 may not count toward the major requirement. At least 2/3 unit of Biology and Biotechnology coursework must be taken from each of three major divisions of biology (below). The 2/3 unit for each division may include courses from any level (1000-4000).
3. • Chosen from among the BB 2000 and 3000 level labs and the Experimental Biochemistry labs, CH 4150.
   • Must include at least 1/2 unit of work at the 2000 level.
4. Chosen from the Related Courses List which includes additional BB 3000/4000 level courses.

THE THREE MAJOR DIVISIONS OF BIOLOGY

1. Cellular and Molecular

BB 1035 Biotechnology
BB 2003 Fundamentals of Microbiology
BB 2550 Cell Biology
BB 2920 Genetics
BB 2950 Molecular Biology
BB 3003 Medical Microbiology
BB 3050 Cancer Biology
BB/CH 4190 Regulation of Gene Expression
BB 4260 Synthetic Biology

2. Biology of the organism

BB 1025 Human Biology
BB 3101 Anatomy and Physiology I
BB 3102 Anatomy and Physiology II
BB 3080 Neurobiology
BB 3120 Plant Physiology
BB 3620 Developmental Biology
BB 3920 Immunology

3. Organisms in their environment

BB 1045 Biodiversity
BB 2030 Plant Diversity
BB 2040 Principles of Ecology
BB 2050 Animal Behavior
BB 3140 Evolution: Pattern and Process

RELATED COURSES

BCB 4002 Biovisualization
BCB 4003 Biological and Biomedical Database Mining
BCB 4004 Statistical Methods in Genetics and Bioinformatics
CE 3059 Environmental Engineering
CH 2330 Organic Chemistry III
CH 3510 Chemical Thermodynamics
CH 4110 Protein Structure and Function
CH 4120 Lipids and Biomemebrane Functions
CH 4130 Nucleic Acids and Bioinformation
CH 4140 Metabolism and Disease
CH 4160 Membrane Biophysics
CHE 3301 Introduction to Biological Engineering
Any BB 3000 or 4000 level course

UNDERGRADUATE RESEARCH PROJECTS

The biology and biotechnology facilities offer an exceptional learning opportunity since research in an active laboratory group is the principal teaching tool. Tools for modern biochemistry, molecular biology, tissue culture, fermentation, ecology, microscopy and computer integration are all available to undergraduates.

In conjunction with the faculty, students who wish to expand their educational opportunities pursue many off-campus projects each year. Investigations may take place at institutions that have traditionally worked with WPI, such as the University of Massachusetts Medical School and Tufts Cummings School of Veterinary Medicine. The department also has established links with several companies that provide opportunities for project work and summer employment in applied biology and biotechnology.

Undergraduate research projects may be proposed by individual students or groups of students, or may be selected from on-going research activities of the faculty. The departmental faculty must be consulted for approval of a project before student work begins.

MINOR IN BIOLOGY

Rather than trying to cover the entire field of biology, the minor in biology has been designed to allow the student to survey a few areas of biology (e.g. ecology and genetics) or to select a specific area of focus (e.g. cell biology) for the minor. In either case, students will complete three courses at the 1000 and 2000 level to provide broad foundational knowledge, two laboratory modules, and two 3000/4000 level courses for advanced study, including a 4000 level course of the student's choosing. Students should choose their foundational courses carefully so that they provide recommended background for upper level courses they plan to take. As with all minors, 1 unit of this work may be double counted toward meeting another degree requirement, while a minimum of 1 unit of the work must be unique to the minor. The specific requirements for the minor are as follows:

REQUIREMENTS	UNITS
1000-level BB course (note 1)	1/3
2000-level BB courses	2/3
BB laboratory courses (note 2)	1/3
3000/4000-level BB course	1/3
4000-level BB course	1/3

NOTE

1. BB 1000, BB 1001, BB 1002, BB/BCB 1003 cannot be used to fulfill this requirement.
2. At least one of the BB laboratory courses must be at the 2000-level.

BIOMEDICAL ENGINEERING

K. L. BILLIAR, HEAD; G. PINS, ASSOCIATE HEAD

PROFESSORS: K. Billiar, G. R. Gaudette, Y. Mendelson, G. D. Pins
ASSOCIATE PROFESSORS: D. Albrecht, S. Ji, M. W. Rolle, K. Troy
ASSISTANT PROFESSORS: J. M. Coburn, A. Lammert, K. Lee, C. F. Whittington, H. Zhang
ASSOCIATE TEACHING PROFESSOR: S. Ambady
ASSISTANT TEACHING PROFESSORS: T.A. Butler, A. Z. Reidinger
PROFESSOR OF PRACTICE: R. L. Page
ASSOCIATED FACULTY: H. Ault (ME), C. Brown (ME), N. Burnham (PH), T. Camesano (CHE), E. Clancy (ECE), T. Dominko (BBT), G. Fischer (ME), M. Fofana (ME), J. King (BBT),S. Liu (ME), F. Looft (ECE), R. Ludwig (ECE), C. Ozaki (BME), A. Peterson (CHE), M. Popovic (PH), S. Roberts (CHE), B. Savilonis (ME), S. Shivkumar (ME), W. Soboyejo (ME), J. Sullivan (ME), D. Tang (MA), E. Tuzel (PH), P. Weathers (BBT), Q. Wen (PH), E. Young (CHE)
EMERITUS PROFESSOR: R. A. Peura

MISSION STATEMENT

The Biomedical Engineering Department prepares students for rewarding careers in the health care industry or professional programs in biomedical research or medicine.

EDUCATIONAL OBJECTIVES

The educational objectives of the Biomedical Engineering Program, which embrace the WPI educational philosophy, are that our alumni 1) have successful careers, 2) apply sound science and engineering principles to impact the field of biomedical sciences in a socially and ethically responsible manner and, 3) will meet the changing needs of the profession through lifelong learning.

STUDENT OUTCOMES

The Biomedical Engineering Program has established the following student outcomes in support of the educational objectives of our department. The general and specific program criteria meet the requirements for Biomedical Engineering accreditation by ABET (The Accreditation Board for Engineering and Technology). Accordingly, students graduating from the Biomedical Engineering Program will demonstrate:

1. An ability to identify, formulate, and solve complex engineering problems at the interface of engineering and biology by applying principles of engineering, science, and mathematics
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. An ability to communicate effectively with a range of audiences
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data from living and non-living systems, and use engineering judgment to draw conclusions
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies
8. An understanding of biology and physiology
9. An ability to address the problems associated with the interaction between living and non-living materials and systems.

Biomedical engineering is the application of engineering principles to the solution of problems in biology and medicine for the enhancement of health care. Students choose this field in order:

- to be of service to people;
- to work with living systems; and
- to apply advanced technology to solve complex problems of medicine.

Biomedical engineers may be called upon to design instruments and devices, to integrate knowledge from many sources in order to develop new procedures, or to pursue research in order to acquire knowledge needed to solve problems. The major culminates in a Major Qualifying Project, which requires that each student apply his or her engineering background to a suitable biomedical problem, generally in association with the University of Massachusetts Medical School, Tufts University School of Veterinary Medicine, one of the local hospitals, or a medical device company.

Each student's program will be developed individually with an advisor to follow the Biomedical Engineering program chart. WPI requirements applicable to all students must also be met. See page 7.

Biomedical engineering is characterized by the following types of activity in the field:

1. Uncovering new knowledge in areas of biological science and medical practice by applying engineering methods;
2. Applying engineering principles to identify unmet needs in the medical and biological fields and implement high impact innovative solutions;
3. Designing and developing patient-related instrumentation, biosensors, prostheses, biocompatible materials, and diagnostic and therapeutic devices; and bioengineered tissues and organs;
4. Analyzing, designing, and implementing improved health-care delivery systems and apparatus in order to improve patient care and reduce health-care costs in contexts ranging from individual doctors' offices to advanced clinical diagnostic and therapeutic centers.

The modeling of biological systems is an example of applying engineering analytical techniques to better understand the dynamic function of biological systems. The body has a complex feedback control system with multiple subsystems that interact with each other. The application of modeling, computer simulation, and control theory provides insights into the function of these bodily processes.

Recently, there has been increased emphasis on the application of the biomedical engineering principles embodied in the third and fourth areas listed above. Examples of the third area include:

- designing and developing tissues and organs;
- development of implantable biomaterials;
- design of an implantable power source;
- design of transducers to monitor the heart's performance;
- development of electronic circuitry to control the system;
- bench and field testing of devices in animals;
- application of new technology to rehabilitation engineering.

The fourth area involves closer contact with the patient and health-care delivery system. This area is commonly referred to as Clinical Engineering. The engineer in the clinical environment normally has responsibility for the medical instrumentation and equipment including:

- writing procurement specifications in consultation with medical and hospital staff;
- inspecting equipment for safe operation and conformance with specifications;
- training medical personnel in proper use of equipment;
- testing within hospital for electrical safety; and
- adaptation of instrumentation to specific applications.

Biomedical engineering projects are available in WPI's Goddard Hall and Higgins Laboratories, the Life Sciences and Bioengineering Center at Gateway Park as well as at the affiliated institutions previously listed.

Program Distribution Requirements for the Biomedical Engineering Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7), a biomedical engineer needs a solid background in mathematics, physical and life sciences. The distribution requirements are satisfied as follows:

BIOMEDICAL ENGINEERING	MINIMUM UNITS
1. Mathematics (See Note 1)	6/3
2. Basic Science (See Note 2)	6/3
3. Supplemental Science (See Note 3)	1/3
4. Computer Science (Note 4)	1/3
5. Biomedical Engineering and Engineering (See Note 5)	14/3
6. MQP (See Note 6)	3/3

NOTES:

1. Mathematics must include differential and integral calculus, differential equations and statistics.
2. 2/3 unit from each of the following areas: BB, CH and PH. At least 1/3 unit of BB coursework must be 2000+ level.
3. 1/3 additional unit from BB, CH, PH or FY courses that satisfy BB, CH, or PH.
4. 1/3 unit in basic computer programming (BME 1004, or equivalent).
5. 14/3 unit of engineering coursework as specified in the WPI Catalog "Courses Qualifying for Engineering Department Areas" with the following distribution:
   A. 3/3 unit of 2000+ level in engineering.
   B. 2/3 unit of 3000+ level in engineering.
   C. 9/3 units in Biomedical Engineering which must include the following:
      a. 1/3 unit biomechanics or biofluids at the 2000+ level
      b. 1/3 unit biomaterials or tissue engineering at the 2000+ level
      c. 1/3 unit biosensors or bioinstrumentation at the 2000+ level
      d. 1/3 unit experimental measurement and data analysis at the 2000+ level
      e. 2/3 unit of BME laboratories at the 3000+ level (four 1/6 unit labs)
      f. 1/3 unit BME engineering with living systems laboratory (BME 3111 or equivalent)
      g. 1/3 unit BME design (BME 3300 or equivalent)
      h. 1/3 unit BME elective
      Notes:
      i. 2/3 unit in BME must be at or above the 4000-level, of which 1/3 unit must be at the 4000-level.
      ii. Only 1/3 unit may be ISU (syllabus and final report required)
      iii. MQP credits cannot be used to satisfy the 14/3 engineering coursework)
6. Must include a minimum of 1/3 unit Capstone Design Experience.
   A. Each Biomedical Engineering student must complete a Capstone Design experience requirement. The Capstone Design experience is partially or fully accomplished by completing the Major Qualifying Project which integrates the past course work and involves significant engineering design. At the time of registration for the MQP, the project advisor will determine whether the MQP will meet the full 1/3 unit Capstone Design requirement or not. If not, the advisor will identify an additional 1/6 unit of course work in the area of engineering design (BME 4300 or equivalent) to be taken in order to meet the ABET Capstone Design requirement.

These distribution requirements in *Biomedical Engineering* apply to all students matriculating at WPI AY2012 and after. Students who matriculated prior to AY2012 have the option of satisfying the degree requirements in the catalog current at the time of their matriculation.

BIOMEDICAL ENGINEERING PROGRAM CHART

13/3 UNITS

BASIC SCIENCE AND MATHEMATICS	
Mathematics (MA): 6/3 units, including differential equations and statistics	
Biology (BB): 2/3 units	Physics (PH): 2/3 units
Chemistry (CH): 2/3 units	Supplemental Science: 1/3 unit

1/3 UNIT

COMPUTER PROGRAMMING
1/3 unit Computer Programming/Logic

9/3 UNITS

BIOMEDICAL ENGINEERING	
For Breadth in BME **4/3 unit BME core** • Biomechanics • Biomaterials • Bioinstrumentation • BME Measurement and Analysis **1/3 unit Design** **1/3 unit BME elective**	**1/3 unit engineering with living systems laboratory**† **2/3 units BME laboratories at ≥ 3000-level** (4–1/6 unit labs) **For Depth in BME** **Notes about 9/3 units:** • 1000-level courses do not satisfy requirement • 1/3 unit at ≥ 4000-level • 1/3 unit at 4000-level

† BME 3111 or equivalent

5/3 UNITS

ENGINEERING
Engineering: 1 unit at ≥ 2000-level
Engineering: 2/3 units at ≥ 3000-level

2 UNITS

HUMANITIES
See undergraduate catalog

2/3 UNITS

SOCIAL SCIENCE
See undergraduate catalog

1 UNIT

IQP
See undergraduate catalog

1 UNIT

MQP
See undergraduate catalog Must include a minimum of 1/3 unit Capstone Design

2/3 UNITS

FREE ELECTIVES
See undergraduate catalog

1/3 UNIT

PHYSICAL EDUCATION
See undergraduate catalog

Course selections that meet the requirements for BME core knowledge

Biomechanics/ Biofluids	Biomaterials/Tissue Engineering	Bioinstrumentation/ Biosensors	Measurement and Data Analysis
BME 2511 BME 3610 ES 2501 ES 2502 ES 2503 ES 3004	BME 2811 ES 2001	BME 2210 ECE 2010	BME 2211 ME 3901

BIOMEDICAL ENGINEERING SPECIALIZATIONS

Because BME is such a broad and diverse discipline, it is convenient to subdivide it into a number of different specializations, or tracks. At the undergraduate level, these specializations help to bring focus to course and project planning. At the graduate-level, these specializations are aligned with the research interests of our faculty. Here at WPI, three specializations have been defined: 1) Biomechanics, 2) Biomedical Instrumentation, Biosignals and Image Processing, and 3) Biomaterials and Tissue Engineering. If students are interested in developing an undergraduate program of study in one of these specializations, they should consult the Program of Study in BME sections of the catalog, within their chosen areas of specialization. See the department web site for more details.

BIOMECHANICS

Biomechanics is a specialization within biomedical engineering that involves the application of engineering mechanics to the study of biological tissues and physiological systems. When most people first think of biomechanics, the way we move or the strength of bones generally comes to mind. However, many other aspects are included in this diverse field of study including:

- Dynamics – e.g., analysis of human movement including walking, running, and throwing.
- Statics – e.g., determination of the magnitude and nature of forces in joints, bones, muscles and implanted prostheses, and characterization of the mechanical properties of the tissues in our bodies.
- Stress Analysis – e.g. calculation of the stresses and deformations within biological tissues and prostheses, and characterization of the mechanical properties of tissues and biomaterials.
- Fluid mechanics and transport – e.g., analysis flow of blood through arteries and air through the lung and diffusion of oxygen in tissues.

Biomechanics research has improved our understanding of:

- Design and manufacturing of medical instruments, devices for disabled persons, artificial replacements, and implants.
- Human performance in the workplace and in athletic competition.
- Normal and pathological human and animal locomotion.
- The mechanical properties of hard and soft tissues.
- Neuromuscular control.
- The connection between blood flow and arteriosclerosis.
- Air flow and lung pathology.
- The effects of mechanical loads on cellular mechanics and physiology.
- Morphogenesis, growth, and healing.
- The mechanics of biomaterials.
- Engineering of living replacement tissue (tissue engineering).

BIOMEDICAL INSTRUMENTATION, BIOSIGNALS AND IMAGE PROCESSING

BIOINSTRUMENTATION

Modern health care relies heavily on a large array of sophisticated medical instrumentation and sensors to diagnose health problems, to monitor patient condition and administer therapeutic treatments, most often in a non-invasive or minimally-invasive manner. During the past decade, computers have become an essential part of modern bioinstrumentation, from the microprocessor in a single-purpose wearable instrument used to achieve a variety of small tasks to more sophisticated desk-top instruments needed to process the large amount of clinical information acquired from patients. The Biomedical Instrumentation track of our program is focused on training students to design, test, and use sensors and biomedical instrumentation to further enhance the quality of health care. Emphasis is placed both on understanding the physiological systems involved in the generation of the measured variable or affected by therapeutic equipment, as well as the engineering principles of biomedical sensors and biomedical devices.

Examples of common biomedical instrumentations used routinely in medicine include:

- Specialized instrumentation for genetic testing.
- Electrocardiography to measure the electrical activity of the heart.
- Electroencephalography to measure the electrical activities of the brain.
- Electromyography to measure the electrical activities of muscles.
- Mechanical respirators.
- Cardiac pacemakers.
- Defibrillators.
- An artificial heart.
- Heart-lung machines.
- Pulse oximeters.
- Drug infusion and insulin pumps.
- Electrosurgical equipment.
- Anesthesia equipment.
- Kidney dialysis machines.
- Artificial electronic prosthetics used by disabled people (e.g. hearing aids).
- Laser systems for minimally invasive surgery.

BIOSIGNALS

Biosignal processing involves the collection and analysis of data from patients or experiments to identify and extract distinct components of the data set that may lead to better understanding of the processes involved in physiological regulation. For example, identifying and quantifying differences in the dynamic characteristics of physiological function between normal and diseased conditions utilizing biosignal processing techniques may lead to a better understanding of the role of regulatory imbalance in diseased conditions, and should have important clinical and diagnostic and prognostic application.

Examples of biosignal processing include:

- Detection of malignant heart rhythms from electrocardiograms.
- Early detection of sudden cardiac death.
- Monitoring of vital signs.
- Seizure detection using electroencephalogram recordings.
- Real-time control of artificial prosthetics.
- Real-time control of robotic movements.
- Early detection of hypertension and onset of diabetes.
- Wireless transmission of diagnostic devices.
- Modeling of pharmacokinetics and design of algorithms for robust drug delivery.
- Bioinformatics.
- Pattern recognition and decision support systems.
- Artificial intelligence.

IMAGE PROCESSING

Biomedical image processing involves the application of quantitative science and engineering to detect and visualize biological processes. An important area is the application of these tools to the study of diseases with an ultimate goal of aiding medical intervention. While x-ray imaging is an obvious and familiar example with tremendous diagnostic utility, it represents only a small aspect of this important field. Biomedical engineers are active participants in the development of new imaging modalities to acquire and process images from the body, most often in a non-invasive or minimally-invasive manner.

Examples of biomedical imaging and image processing include:

- X-ray imaging and computer-aided tomography (CAT).
- Visible light and optical imaging.
- Near-infrared imaging.
- Magnetic resonance imaging (MRI).
- Ultrasound imaging.
- Nuclear medicine imaging.
- Luminescence-based imaging.

BIOMATERIALS AND TISSUE ENGINEERING

BIOMATERIALS

Biomaterials is a specialization within biomedical engineering that integrates engineering fundamentals in materials science with principles of cell biology, chemistry and physiology to aid in the design and development of materials used in the production of medical devices. When most people first think of biomaterials, implants such as surgical sutures, artificial hips or pacemakers generally come to mind, but many other aspects are included in this diverse field of study:

- Biomaterials Design – Identify the physiological and engineering criteria that an implantable biomaterial must meet. Select the proper chemical composition to insure that the biomaterial imparts the desired mechanical properties and evokes the appropriate tissue response for the specified application.
- Mechanics of Biomaterials – Characterize the magnitude and nature of the mechanical properties of biomaterials. Predict and measure how the physical/structural properties of a biomaterial determine its mechanical properties.
- Biomaterials-Tissue Interactions – Examine the molecular, cellular and tissue responses to implanted medical devices. Design biomaterials with properties that induce the desired wound healing and tissue remodeling responses from the body.

Biomaterials research and development has improved our health care in many ways including:

- Design and manufacture of replacements parts for damaged or diseased tissues and organs (e.g., artificial hip joints, kidney dialysis machines)
- Improved wound healing (e.g., sutures, wound dressings)
- Enhanced performance of medical devices (e.g., contact lenses, pacemakers)
- Correct functional abnormalities (e.g., spinal rods)
- Correct cosmetic problems (e.g., reconstructive mammoplasty, chin augmentation)
- Aid in clinical diagnostics (e.g., probes and catheters)
- Aid in clinical treatments (e.g., cardiac stents, drains and catheters)
- Design biodegradable scaffolds for tissue engineering (e.g., dermal analogs)

TISSUE ENGINEERING

Tissue engineering integrates the principles and methods of engineering with the fundamentals of life sciences towards the development of biological substitutes to restore, maintain or improve tissue/organ function. When most people first think of tissue engineering, artificial skin and cartilage generally comes to mind, but many other aspects are included in this diverse field of study:

- Scaffold/Biomaterial Design – Identify the physiological and engineering criteria that a biodegradable scaffold must meet. Select the proper biochemical composition to insure that the cells perform in a physiologic manner on the surface of the scaffold.
- Functional/Biomechanical Tissue Engineering – Characterize the roles of biomechanical and biochemical stimuli on the formation, growth, development and function of bioengineered cells, tissues and organs. Create accurate biomimetic engineered tissue models of human disease to aid in the discovery, invention and development of novel therapeutic strategies.
- Bioreactor Design – Design reactors that control the rates at which nutrients and growth factors are supplied to bioengineered tissues and organs during growth and development in a laboratory environment.

BUSINESS, ROBERT A. FOISIE SCHOOL OF

S. TAYLOR, DEAN AD INTERIM
D.M. STRONG, DEPARTMENT HEAD AD INTERIM
M.B. ELMES, PROGRAM DIRECTOR (MBA & MS IN MANAGEMENT PROGRAMS)
S. DJAMASBI, PROGRAM DIRECTOR (MS IN INNOVATION WITH USER EXPERIENCE)
A. HALL-PHILLIPS, PROGRAM DIRECTOR (UNDERGRADUATE PROGRAMS & MS IN MARKETING AND INNOVATION)
S. JOHNSON, PROGRAM DIRECTOR (INDUSTRIAL ENGINEERING AND MS IN OPERATIONS ANALYTICS & MANAGEMENT)
E. LOIACONO, PROGRAM DIRECTOR (MS IN INFORMATION TECHNOLOGY)
J. SARKIS, PROGRAM DIRECTOR (MS IN SUPPLY CHAIN MANAGEMENT)
J. ZHU, PROGRAM DIRECTOR (PHD PROGRAM)

PROFESSORS: S. Djamasbi, M.B. Elmes, H.N. Higgins, F. Hoy, S.A. Johnson, E. Loiacono, J. Sarkis, D.M. Strong, S. Taylor, J. Zhu
ASSOCIATE PROFESSORS: A. Hall-Phillips, R. Konrad, F. Miller, A. Trapp, B. Tulu
ASSISTANT PROFESSORS: K. Ching, N. Kordzadeh, E. Long Lingo, S. Saberi, P. Shah
PROFESSORS OF PRACTICE: R. Sarnie, S. Wulf
ASSOCIATE TEACHING PROFESSORS: J. Ryan, W. Towner, E.V. Wilson

MISSION

Inspiring leaders at the
Nexus of
Science, Engineering, and Business with
Project-based, purpose-driven learning and
Innovative research to achieve impactful
Results and to pursue
Excellence that drives progress.

VISION

The leading business school focused on research and education at the intersections of STEM, business, and human behavior to solve global problems.

COURSE AREAS

The Robert A. Foisie School of Business covers all the functional areas of business. Courses with the following prefixes are found within the School:

ACC Accounting
BUS Business, including all foundation courses
ETR Entrepreneurship
FIN Finance
MIS Management Information Systems
MKT Marketing
OIE Operations & Industrial Engineering
OBC Organizational Behavior and Change

BUSINESS (BU)

EDUCATIONAL OBJECTIVES

Objectives of the Business Major are:

- To prepare students for management roles in technology-based organizations.
- Through a flexible curriculum, to provide a solid, broad base of business knowledge and the written communication, oral presentation, decision-making, and leadership skills necessary to succeed in a technology-based environment.
- To develop student abilities necessary for continued career growth including:
  - the ability to integrate theory and practice;
  - the ability to integrate technology and change into existing organizations;
  - the ability to think critically and analytically, to define and solve business problems, work in teams, and think globally; and
  - the ability to learn new skills in response to changing professional requirements.

Program Distribution Requirements for the Business Major

REQUIREMENTS (NOTE 1)	MINIMUM UNITS
1. Business Foundation (Note 2)	11/3
2. Mathematics (Note 3)	4/3
3. Basic Science	2/3
4. Business Major (Note 4)	6/3
5. Breadth Electives (Note 5)	3/3
6. Computer Science (Note 6)	1/3
7. BU MQP	3/3

NOTES:

1. Courses may not be counted more than once in meeting these distribution requirements.
2. The Business Foundation consists of BUS 1010: Leadership Practice; BUS 1020: Global Environment of Business Decisions; BUS 2020: The Legal Environment of Business Decisions; BUS 2060: Financial Statements for Decision Making; BUS 2070: Risk Analysis for Decision Making; BUS 2080: Data Analysis for Decision Making; BUS 3010: Creating Value through Innovation; BUS 3020: Achieving Effective Operations; BUS 4030: Achieving Strategic Effectiveness. Microeconomics and Macroeconomics are required and also fulfill the WPI Social Science requirement.
3. Mathematics must include 2/3 units of calculus and 2/3 units of statistics.
4. Students selecting the Business Major must complete six courses from one of the concentrations as specified in the summary table for concentrations on page 46. Students may also work with their academic advisor to create a custom BU Program. Such custom programs must be approved by the advisor and the Business School's Undergraduate Policy and Curriculum Committee.
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
6. A minimum of 1/3 unit of Computer Science focused on programming. CS 1004, CS 1101, or CS 1102 is recommended. (CS 2022 and CS 3043 are not accepted.)

BUSINESS/MANAGEMENT ENGINEERING/MANAGEMENT INFORMATION SYSTEMS OVERVIEW OF DEGREE REQUIREMENTS

UNIVERSITY REQUIREMENTS
HUMANITIES AND ARTS (6/3 Units): 6 courses including Inquiry Seminar/Practicum
SOCIAL SCIENCE (2/3 Units): ECON 1110* & ECON 1120*
PHYSICAL EDUCATION (1/3 Units)
INTERACTIVE QUALIFYING PROJECT (3/3 Unit)-3rd Year

MATHEMATICS AND SCIENCE REQUIREMENTS
BASIC SCIENCE (2/3 Units) BB, CH, GE, PH
MATHEMATICS (4/3 Units) Calculus - MA 1021; MA 1022; Statistics - MA 2611; MA 2612
COMPUTER SCIENCE (1/3 Units): CS 1004 (recommended) or CS 1101 or CS 1102

CORE BUSINESS CURRICULUM	
BUSINESS FOUNDATIONS (5/3 Units)	**BUSINESS STRATEGY AND ANALYSIS (6/3 Units)**
ECON 1110 Introductory Microeconomics* ECON 1120 Introductory Macroeconomics* BUS 1010 Leadership Practice BUS 1020 Global Environment of Decision Making BUS 2020 Legal Environment of Business Decisions	BUS 2060 Financial Statements for Decision Making BUS 2070 Risk Analysis for Decision Making BUS 2080 Data Analysis for Decision Making BUS 3010 Creating Value Through Innovation BUS 3020 Achieving Effective Operations BUS 4030 Achieving Strategic Effectiveness

DEGREE CONCENTRATION OPTIONS (6/3 Units) (Please see concentration courses listed on page 46.)		
B.S. in BUSINESS	**B.S. in MANAGEMENT ENGINEERING**	**B.S. in MANAGEMENT INFORMATION SYSTEMS**
CONCENTRATIONS • Business Analytics • Financial Technology (Fintech) • Innovation for Social Change • General Business	**CONCENTRATIONS** • Biomedical Engineering • Chemistry • Civil Engineering • Electrical and Computer Engineering • Manufacturing Engineering • Mechanical Engineering • Operat ons Management • Custom	**CONCENTRATIONS** • Management Information Systems
MAJOR QUALIFYING PROJECT (3/3 Units) **The MQP must have a focus and advisor in the concentration area from the Business School.**		
BREADTH ELECTIVES (3/3 Units)		
Must include 1/3 unit from 3000- and 4000-level FBS courses; Remaining 2/3 units may be satisfied from MA, CS, SS, Basic Science, or with prefixes ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.		
FREE ELECTIVES (5/3 Units)		

*ECON 1110 and ECON 1120 count toward Social Science requirements.

BUSINESS CONCENTRATION COURSES (6/3 Units)			
Business Analytics	**Fintech**	**Innovation for Social Change**	**General Business**
•Select one programming course: CS 2119, CS 2102, or CS 2103 •Select one: MIS 3720 or CS 3431 •Select one Math elective: MA 2071, MA 2621, MA 3231, MA 3627 •Select three business-domain, analytics electives, at least two at the 4000 level: MIS 4084, MIS 4720, MIS 4741, MKT 3650, OIE 3420, OIE 3460, OIE 3600, OIE 4420	•Required: FIN 3300 •Select four: CS 2119 or CS 2102 or CS 2103, MIS 3720, MIS 3787, MIS 4720, MIS 4741 •One 2000-level or higher course from: CS (excluding CS 2022, CS 3043), ECON, FIN, MIS, OIE, and actuarial math courses (MA 2211, MA 2212, MA 2621)	•Required: ETR 2900 •Select three: ETR 3633, ETR 3915, ETR 4930, OBC 4367 •Select two: EN 2251, ENV 2201, ENV 2310, ENV 2400, ENV 2600, GOV 2311, GOV 2312, GOV 2319, HI 2341, HI 2403, INTL 2100, PSY 1402, PY/RE 2731, PY/RE 2732, SD 1510, SOC 1202	Complete six courses from no more than three areas: •Accounting & Finance: FIN 3300 •Economics: ECON 2110, ECON 2117, ECON 2120, ECON 2125, ECON 2130, ECON 2135, ECON 2145, ECON 2155, ECON/ETR 2910 •Entrepreneurship: ETR 2900, ETR/ECON 2910, ETR 3633, ETR 3915, ETR 4930 •Law: GOV 1310, GOV 2310, GOV 2311, GOV 2312, GOV 2313, GOV 2314 •Marketing: MKT 3640, MKT 3650 •Organizational Behavior: BUS 4300, OBC 3354, OBC 4367 •Psychology: PSY 1401, PSY 1402, PSY 1504, PSY 2406

MANAGEMENT ENGINEERING CONCENTRATION COURSES (6/3 Units)			
Biomedical Engineering	**Chemistry**	**Civil Engineering**	**Electrical and Computer Engineering**
•Select one course, but no more than two, from: ETR 2900, ETR 2910, ETR 3915, ETR 4930, MKT 3640, MKT 3650, OIE 3410, OIE 3420, OIE 3510, OIE 3600, OBC 3354, OBC 4367 •Select at least four courses, but no more than five, from: BME 1001, BME 2001, BME 2210, BME 2502, BME 3300, BB 3101, BB 3102	•Select one course, but no more than two, from: ETR 2900, ETR 2910, ETR 3915, ETR 4930, MKT 3640, MKT 3650, OIE 3410, OIE 3420, OIE 3510, OIE 3600, OBC 3354, OBC 4367 •Select at least four courses, but no more than five, from: CH 1030, CH 1040, CH 2310, CH 2320, CH 2330, CH 2360, CH 2640, CH 3510	•Select one course, but no more than two, from: ETR 2900, ETR 2910, ETR 3915, ETR 4930, MKT 3640, MKT 3650, OIE 3410, OIE 3420, OIE 3510, OIE 3600, OBC 3354, OBC 4367 •Select as least four courses, but no more than five, from: AREN 2023, CE 1030, CE2000, CE 2020, CE 3020, CE 3022, CE 3025, CE 3030, CE 3031, CE 3041, ES 3004	•Select one course, but no more than two, from: ETR 2900, ETR 2910, ETR 3915, ETR 4930, MKT 3640, MKT 3650, OIE 3410, OIE 3420, OIE 3510, OIE 3600, OBC 3354, OBC 4367 •Select at least four courses, but no more than five, from: ECE 2010, ECE 2019, ECE 2029, ECE 2049, ECE 2112, ECE 2311, ECE 2312, ECE 2799

MANAGEMENT ENGINEERING CONCENTRATION COURSES (6/3 Units)		
Manufacturing Engineering	**Mechanical Engineering**	**Operations Management**
•Select one course, but no more than two, from: ETR 2900, ETR 2910, ETR 3915, ETR 4930, MKT 3640, MKT 3650, OIE 3410, OIE 3420, OIE 3510, OIE 3600, OBC 3354, OBC 4367 •Select at least four courses, but no more than five, from: ES 2001, ME 1800, ME 2820, ME 3320, ME 3820, ME 4718, ME 4810, ME 4813, ME 4814, ME 4815, ME 4821, ME 4875	•Select one course, but no more than two, from: ETR 2900, ETR 2910, ETR 3915, ETR 4930, MKT 3640, MKT 3650, OIE 3410, OIE 3420, OIE 3510, OIE 3600, OBC 3354, OBC 4367 •Select at least four courses, but no more than five, from: ES 2001, ES 2501, ES 2502, ES 2503, ES 3001, ES 3003, ES 3004, ME 1800, ME 2300, ME 2820, ME 3820, ME 3901 or 3902, ME 4320, ME 4429, ME 4430	•Complete the following four: OBC 3354, OIE 3410, OIE 3420, OIE 4460 •Select two from: CS 2119 or CS 2102/CS 2103, MIS 3720, MKT 3640, MKT 3650, OBC 4367, OIE 2081, OIE 3405, OIE 3460, OIE 3510, OIE 3600, OIE 4410, OIE 4420

MANAGEMENT INFORMATION SYSTEMS CONCENTRATION COURSES (6/3 Units)
Management Information Systems
Complete the following three: MIS 3720, MIS 3787, MIS 4720 Select one of the following: CS 2119, CS 2102 or CS 2103 Select two from: CS 2102 or CS 2103, CS 2301 or CS 2303, CS 3041

MANAGEMENT ENGINEERING (MGE)

EDUCATIONAL OBJECTIVES

Objectives of the Management Engineering Major are:

- To prepare students for management challenges in key areas that increasingly require proficiency in the technical aspects of business such as production and service operations.
- To provide the knowledge and skills necessary to succeed professionally, including literacy in a technical field, a broad understanding of management issues, written communication, oral presentation, decision-making, and leadership skills required to create new and improved products, processes and control systems.
- To develop student abilities necessary for continued career growth including:
  - the ability to integrate theory and practice and to apply knowledge of technical issues with the foundations of management;
  - the ability to integrate technology and change into existing organizations;
  - the ability to think critically and analytically, to define and solve business problems, work in teams, and think globally; and
  - the ability to learn new skills in response to changing professional requirements.

Program Distribution Requirements for the Management Engineering Major

REQUIREMENTS (NOTE 1)	MINIMUM UNITS
1. Business Foundation (Note 2)	11/3
2. Mathematics (Note 3)	4/3
3. Basic Science	2/3
4. Management Engineering Major (Note 4)	6/3
5. Breadth Electives (Note 5)	3/3
6. Computer Science (Note 6)	1/3
7. MGE MQP	3/3

NOTES:

1. Courses may not be counted more than once in meeting these distribution requirements.
2. The Business Foundation consists of BUS 1010: Leadership Practice; BUS 1020: Global Environment of Business Decisions; BUS 2020: The Legal Environment of Business Decisions; BUS 2060: Financial Statements for Decision Making; BUS 2070: Risk Analysis for Decision Making; BUS 2080: Data Analysis for Decision Making; BUS 3010: Creating Value through Innovation; BUS 3020: Achieving Effective Operations; BUS 4030: Achieving Strategic Effectiveness. Microeconomics and Macroeconomics are required and also fulfill the WPI Social Science requirement.
3. Mathematics must include 2/3 units of calculus and 2/3 units of statistics.
4. Students selecting the Management Engineering Major must complete six courses from one of the concentrations as specified in the summary table for concentrations on page 46. Students may also work with their faculty advisor to create a custom MGE Program. Such custom programs must be approved by the advisor and the Business School's Undergraduate Policy and Curriculum Committee.
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
6. A minimum of 1/3 unit of Computer Science focused on programming. CS 1004, CS 1101, or CS 1102 is recommended. (CS 2022 and CS 3043 are not accepted.)

MANAGEMENT INFORMATION SYSTEMS (MIS)

EDUCATIONAL OBJECTIVES

The objectives of the Management Information Systems major are:

- To prepare students for positions involving the design and deployment of business applications using a wide variety of advanced information technologies, especially in high technology business, consulting, and service firms, in either start-up or established environments, and to prepare students for rapid advancement to project management and other management positions.
- To provide the knowledge and skills consistent with the professionally accepted IS curriculum guidelines. Specifically, this includes providing knowledge and skills related to:
  - business application development tools;
  - database, web-based and machine learning applications;
  - integrating IT into existing organizations through managing and leading systems analysis and design projects;
  - communicating effectively via written and oral presentations.
- To develop student abilities necessary for continued career growth including:
  - the ability to integrate theory and practice and to apply knowledge of information technology issues with the foundations of management;
  - the ability to integrate technology and change into existing organizations;
  - the ability to think critically and analytically, to define and solve business problems, work in teams, and think globally; and
  - the ability to learn new skills in response to changing professional requirements.

Program Distribution Requirements for the Management Information Systems Major

REQUIREMENTS (NOTE 1)	MINIMUM UNITS
1. Business Foundation (Note 2)	11/3
2. Mathematics (Note 3)	4/3
3. Basic Science	2/3
4. Management Information Systems Major (Note 4)	6/3
5. Breadth Electives (Note 5)	3/3
6. Computer Science (Note 6)	1/3
7. MIS MQP	3/3

NOTES:

1. Courses may not be counted more than once in meeting these distribution requirements.

2. The Business Foundation consists of BUS 1010: Leadership Practice; BUS 1020: Global Environment of Business Decisions; BUS 2020: The Legal Environment of Business Decisions; BUS 2060: Financial Statements for Decision Making; BUS 2070: Risk Analysis for Decision Making; BUS 2080: Data Analysis for Decision Making; BUS 3010: Creating Value through Innovation; BUS 3020: Achieving Effective Operations; BUS 4030: Achieving Strategic Effectiveness. Microeconomics and Macroeconomics are required and also fulfill the WPI Social Science requirement.
3. Mathematics must include 2/3 units of calculus and 2/3 units of statistics.
4. Students selecting the Management Information Systems major must complete six courses as specified in the summary table on page 46.
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
6. A minimum of 1/3 unit of Computer Science focused on programming. CS 1004, CS 1101, or CS 1102 is recommended. (CS 2022 and CS 3043 are not accepted.)

INDUSTRIAL ENGINEERING

PROGRAM MISSION

The mission of the Industrial Engineering (IE) Program at WPI is to prepare undergraduate students for professional engineering practice, providing the foundation for careers of leadership in challenging global and technological environments. We strive to accomplish this through:

- An innovative, project-based curriculum
- An emphasis on industrial engineering skills with system applications
- A flexible curriculum responsive to student interests and changes in the competitive environment
- An environment that encourages faculty/student interaction
- A culture that encourages the active involvement of students in their learning

PROGRAM EDUCATIONAL OBJECTIVES

The educational objectives of the IE Program describe the expected accomplishments of graduates during the first few years after graduation. They include:

Industrial Engineering Knowledge and Design Skills. Graduates should be able to support operational decision making and to design solutions that address the complex and changing industrial engineering problems faced by organizations, using current concepts and technologies.

Communication Skills. Graduates will be sought out as the preferred employees to represent their companies both for internal and external communications based upon the excellence they will have achieved through persistent updating of their knowledge of new communication tools and by taking advantage of opportunities for critical peer review.

Teamwork and Leadership Skills. Graduates should be able to serve as change agents in a global environment, based on strong interpersonal and teamwork skills, an understanding of professional and ethical responsibility, and a willingness to take initiatives.

STUDENT OUTCOMES

Specifically, graduating students should demonstrate that they attain the following:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Program Distribution Requirements for the Industrial Engineering Major (IE)

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7), students wishing to receive the ABET accredited degree designated "Industrial Engineering" must complete a minimum of 10 units of study in the areas of mathematics, basic science, and engineering topics as follows:

REQUIREMENTS	MINIMUM UNITS
Mathematics and Basic Science (Note 1)	12/3
Industrial Engineering Topics (Note 2)	15/3
Capstone Design Experience (IE MQP)	3/3

NOTES:

1. Mathematics and Basic Science:
   a. Mathematics must include differential and integral calculus, ordinary differential equations, and 2/3 units in probability and statistics.
   b. 3/3 units of Basic Science in chemistry and physics. No GPS credits may be used.
   c. 2/3 units of Math/Science Electives
2. Industrial Engineering Topics must include courses in the following three topic areas:
   a. The IE Core consists of 9/3 units: BUS 3020: Achieving Effective Operations; OIE 2081: Introduction to Prescriptive Analytics; OIE 2850: Engineering Economics; OIE 3405: Work Systems and Facilities Planning or OIE 4420: Practical Optimization; OIE 3410: Materials Management in Supply Chains; OIE 3420: Quality Planning, Design and Control; OIE 3460: Simulation Modeling and Analysis; OIE 3510: Stochastic Models; OIE 3600: Scripting for Process & Productivity Improvement or CS 2119: Application Building with Object-Oriented Concepts or CS 2102: Object-Oriented Design Concepts or CS 2103: Accelerated Object-Oriented Design Concepts.

INDUSTRIAL ENGINEERING
OVERVIEW OF DEGREE REQUIREMENTS

UNIVERSITY REQUIREMENTS
HUMANITIES AND ARTS (6/3 Units): 6 courses including Inquiry Seminar/Practicum
SOCIAL SCIENCE (2/3 Units): ECON, ENV, GOV, SOC, SS, STS, and ID 2050
PHYSICAL EDUCATION (1/3 Units)
INTERACTIVE QUALIFYING PROJECT (3/3 Unit)-3rd Year

MATHEMATICS AND SCIENCE REQUIREMENTS
MATHEMATICS (7/3 Units) Calculus - MA 1021; MA 1022; MA 1023, MA 1024, MA 2051 Statistics - MA 2611; MA 2612 or 2621
PHYSICS/CHEMISTRY (3/3 Units) CH, PH, CH or PH
MATH/SCIENCE ELECTIVES (2/3 Units) Recommended Math: MA 2071, probability & stats., numerical analysis Science BB, CH, GE, PH

INDUSTRIAL ENGINEERING CORE CURRICULUM (9/3 Units)	
BUS 3020 Achieving Effective Operations	OIE 3410 Materials Management in Supply Chains
OIE 2081 Introduction to Prescriptive Analytics	OIE 3420 Quality Planning, Design and Control
OIE 2850 Engineering Economics	OIE 3460 Simulation Modeling and Analysis
OIE 3405 Work Systems and Facilities Planning **or** OIE 4420 Practical Optimization: Methods & Applications	OIE 3510 Stochastic Models
	OIE 3600 Scripting for Process & Productivity Improvement **or** CS 2119 **or** CS 2102 **or** CS 2103

INDUSTRIAL ENGINEERING ELECTIVES-Operations Research (3/3 Units)
Choose three: OIE 3405*, OIE 3600*, OIE 4410, OIE 4420*, OIE 4460, MIS 3720, MIS 4084, MIS 4720, MIS 4741, MA 3231, MA 3233, MA 3627, MA 3631, MA 4235, MA 4237, MA 4631, MA 4632. **Only if not taken in IE Core.*
TECHNICAL ELECTIVES (3/3 Units)
Any designated CE (except CE 3022), CHE, CS (except CS 1004, 1101, 1102, 3043), ECE, ES (except ES 1000, 3323), ME, OIE, RBE, as well as any IE Elective (see above). Suggested courses include: CS 2011, CS 4032/MA 3257, ECE 2010, ES 1310, ES 2001, ES 2800, ES 3001, ME 1800, ME 2820. ***One ES course required.*** *GPS course credits do not qualify.*
MAJOR QUALIFYING PROJECT (3/3 Units) **The MQP must have an IE faculty advisor from the Business School.**
FREE ELECTIVES (3/3 Units)

b. IE Electives (3/3 units): Any 3000- or 4000-level Operations Research courses in MA; MIS 3720, 4084, 4720, 4741; OIE 3405*, 3600*, 4410, 4420*, 4460.

*Only if not taken in IE Core.

c. Technical Electives (3/3 units): Any Engineering Science/Design course qualifies (except ES 1000 and ES 3323), as well as any CE (except CE 3022), CHE, CS (except CS 1004, 1101, 1102 & 3043), ECE, ME, OIE and RBE. **At least one course in ES is required for meeting this requirement**. Suggested courses include: CS 2011, CS 4032/MA 3257, ECE 2010, ES 1310, ES 2001, ES 2800, ES 3001, ME 1800, ME 2820. No GPS credits may be used.

MINOR IN BUSINESS

Everyone needs management skills. If engineers, scientists, and others hope to advance in their careers, they must learn how to lead projects and manage groups. The Business minor offers students (other than BU, MGE, or MIS majors, who may take the courses as part of their major or as Breadth or Free Electives, as appropriate) the opportunity to learn some of the theory and practice of managing in organizations with material on management concepts and practices commonly encountered in the business world. This program will help students make a transition to the business world and will provide basic skills for operating effectively in business organizations.

To complete the Business minor, a student must complete two units of work, typically through course work with the following distribution:

1. Select any **five** from the following:
   ECON 1110 **OR** ECON 1120
   BUS 1010 Leadership Practice
   BUS 1020 Global Environment of Business Decisions
   BUS 2020 The Legal Environment of Business Decisions
   BUS 2060 Financial Statements for Decision Making
   BUS 2070 Risk Analysis for Decision Making
   BUS 2080 Data Analysis for Decision Making
   BUS 3010 Creating Value through Innovation
   BUS 3020 Achieving Effective Operations
2. Select **one** of the following two courses:
   BUS 4030 Achieving Strategic Effectiveness
   ETR 4930 Growing and Managing New Ventures

The minor in Business is available to all students at WPI, except for those majoring in Business, Management Engineering or Management Information Systems majors at WPI.

For general policy on minors, see page 11 of the catalog.

MINOR IN ENTREPRENEURSHIP

All around the world people are starting their own new business ventures. With its strong heritage of invention and entrepreneurship among students and faculty members, WPI is committed to encouraging its students to consider that career path. Our dream is that our students will earn a minor in Entrepreneurship, which will provide them with some basic business skills and an understanding of what it takes to start a business, then they will create a new and exciting technology as their MQP that they will then turn into a business upon graduation.

Related opportunities include competitions for the following: The Robert H. Grant Invention Awards, the Strage Innovation Awards, and the Kalenian Award. Through the Collaborative for Entrepreneurship and Innovation, WPI sponsors the student entrepreneurship club, Tech Entrepreneurs, and promotes and sponsors MassChallenge.

The minor requires the completion of two units of coursework as noted below.

1. Complete the following course:
   BUS 2060 Financal Statements for Decision Making
2. Complete two (2) from the following list:
   ETR 1100 Engineering Innovation and Entrepreneurship
   ETR 2900 Social Entrepreneurship
   ETR 3633 Entrepreneurial Selling
   ETR 3915 Entrepreneurial Business Models
3. Complete two (2) of the following courses:
   BUS 2070 Risk Analysis for Decision Making
   BUS 3010 Creating Value through Innovation
   MKT 3640 Management of Process and Product Innovation
   GOV 2313 Intellectual Property Law
4. Required:
   ETR 4930 Growing and Managing New Ventures

The minor in Entrepreneurship is available to all students at WPI, regardless of major.

For general policy on minors, see page 11 of the catalog.

MINOR IN INDUSTRIAL ENGINEERING

Industrial Engineering is concerned with efficiency and process improvement, which are vital to any organization's survival and growth in a global, competitive world. Hence, the fundamental skills and knowledge of Industrial Engineering can be utilized in many areas, and are valuable supplements to a student's core competency in his/her chosen major discipline. The IE minor provides an easy link between the curricula in engineering and business and expands students' ability to tackle business decisions and problems using engineering techniques.

The minor requires the completion of two units of coursework (six courses) as noted below.

1. IE Tools, select at least two (2):
   OIE 2081 Introduction to Prescriptive Analytics
   OIE 2850 Engineering Economics
   OIE 3460 Simulation Modeling and Analysis
   OIE 3510 Stochastic Models
   OIE 3600 Scripting for Process & Productivity Improvement
   OIE 4420 Practical Optimization: Methods and Applications
2. IE Knowledge, select at least two (2):
   BUS 3020 Achieving Effective Operations
   OIE 3405 Work Systems and Facilities Planning
   OIE 3410 Materials Management in Supply Chain
   OIE 3420 Quality Planning, Design, and Control
   OIE 4410 Case Studies in Industrial Engineering
   OIE 4460 Global Planning and Logistics

The minor in Industrial Engineering is available to all students at WPI, except for those majoring in Industrial Engineering.

For general policy on minors, see page 11 of the catalog.

MINOR IN MANAGEMENT INFORMATION SYSTEMS

Information technology has been the driving force behind the new way of doing business. It has enabled companies to make tremendous strides in productivity, it has opened new markets and new channels, and it has created new product and service opportunities. While one part of the information revolution has been advances in hardware, and another has been advances in software, a third major advance has been in the systems-side of information, or how information is organized and used to make effective decisions. That is Management Information Systems (MIS). The minor in MIS offers students the opportunity to broaden their disciplinary program with material and skills widely useful in the business world. This program will help students to broaden their exposure to information technology and its use in business and industry.

To complete the Management Information Systems minor, a student must complete two units of work with the following distribution:

1. A total of **three (3)** courses in Business Foundation and Programming Skills, with at least **one (1)** from each group:
   A. Business Foundation:
   BUS 1010 Leadership Practice
   BUS 1020 Global Environment of Business Decisions
   BUS 2020 The Legal Environment of Business Decisions
   BUS 2060 Financial Statements for Decision Making
   BUS 2070 Risk Analysis for Decision Making
   BUS 2080 Data Analysis for Decision Making
   BUS 3010 Creating Value through Innovation
   BUS 3020 Achieving Effective Operations
   BUS 4030 Achieving Strategic Effectiveness
   B. Programming Skills:
   CS 1004 Introduction to Programming for Non-Majors **or**
   CS 1101 Introduction to Program Design **or**
   CS 1102 Accelerated Introduction to Program Design
   CS 2102 Object-Oriented Design Concepts **or**
   CS 2103 Accelerated Object-Oriented Design Concepts
   CS 2119 Application Building with Object-Oriented Concepts
   CS 2301 Systems Programming for Non-Majors **or**
   CS 2303 Systems Programming Concepts
2. **Two (2)** courses from the group of courses:
   MIS 3720 Management of Data
   MIS 3787 Business Applications of Machine Learning
   MIS 4084 Business Intelligence
   MIS 4741 User Experience and Design
   MIS 4781 Information Systems and Technology Policy and Strategy
3. Required:
   MIS 4720 Systems Analysis and Design

The minor Management Information Systems is available to all students at WPI, except for those majoring in Management Information Systems.

For general policy on minors, see page 11 of the catalog.

MINOR IN SOCIAL ENTREPRENEURSHIP

Social Entrepreneurship is defined as the formation of a new venture that combines social goals and for-profit activity to address social needs through novel solutions. Social entrepreneurs are leaders in that to be effective, they have to identify social problems, work closely with key stakeholders in identifying solutions to those problems, offer a vision for change, communicate clearly and persuasively to others, negotiate for resources from both public and private concerns, involve people in the solutions to problems, and be creative passionate, and persistent in how they work through various obstacles to progress. It is the purpose of the Social Entrepreneurship minor to provide students with the theoretical underpinnings of leadership, entrepreneurship, and social innovation. This minor will interest those students for whom the Great Problem Seminar and/or IQP have been an eye-opening experience and who aspire to change the world — or some part of it.

The minor requires the completion of two units of coursework as outlined below.

1. Required:
   BUS 1010 Leadership Practice
2. Select two (2):
   ETR 2900 Social Entrepreneurship
   ETR 3633 Entrepreneurial Selling
   ETR 3915 Entrepreneurial Business Models
   ETR 4930 Growing and Managing New Ventures
3. Select two (2):
   BUS 1020 Global Environment of Business Decisions
   BUS 2020 Legal Environment of Business Decisions
   ENV 1100 Introduction to Environmental Studies
   ENV 2400 Environmental Problems and Human Behavior
   ENV 2600 Environmental Problems in the Developing World
   ENV 4400 Senior Seminar in Environmental Studies
   OBC 3354 Organizational Behavior and Change
   PSY 1402 Social Psychology
   PSY 2406 Cross-Cultural Psychology
   SOC 1202 Introduction to Sociology and Cultural Diversity
4. Required:
   OBC 4367 Leadership, Ethics, and Social Responsibility
   (or a suitable ISU)

The minor in Social Entrepreneurship is available to all students at WPI, regardless of major.

For general policy on minors, see page 11 of the catalog.

CHEMICAL ENGINEERING

S. ROBERTS, HEAD

ROFESSORS: T. A. Camesano, R. Datta, A. G. Dixon, N. K. Kazantzis, S. Roberts, J. Wilcox
ASSOCIATE PROFESSORS: W. M. Clark, N. A. Deskins, D. DiBiasio, M. T. Timko, H. Zhou
ASSISTANT PROFESSORS: E. Stewart, A. Teixeira, E. Young
PROFESSOR OF PRACTICE: S. J. Kmiotek
ASSOCIATE TEACHING PROFESSOR: W. Zurawsky
ASSISTANT TEACHING PROFESSOR: L. Abu-Lail
ASSISTANT RESEARCH PROFESSORS: G. Tompsett, S. Liguori
ADJUNCT INSTRUCTOR: B. Partopour, T. Starr
ASSOCIATED FACULTY: J. Bergendahl (CEE), J. Coburn (BME), N. Dembsey (FPE), R. Grimm (CBC), D. Lados (ME), J. Liang (ME), G. Pins (BME), P. Rao (ME), R. Rao (BBT), A. Rangwalla (FPE), K. Rashid, L. Titova (PH), Y. Wang (ME)
EMERITUS FACULTY: Y. H. Ma, W. R. Moser, R. W. Thompson, H. Weiss

MISSION STATEMENT

To prepare technically advanced, socially aware and interdisciplinary-minded chemical engineers. Our graduates will be ready to serve the global community as leaders, scholars and innovators.

VISION STATEMENT

WPI's chemical engineering department will be a national leader in innovating and implementing curricula, project work and research that infuses global, entrepreneurial and humanitarian perspectives.

PROGRAM EDUCATIONAL OBJECTIVES

The Chemical Engineering Department has established the following objectives of the undergraduate program in support of our mission and that of the Institute. Graduates are expected to be able to attain these objectives within 5 years following graduation:

1. Graduates will be able to use chemical engineering principles to solve problems of practical importance to society.
2. Graduates will be productive and informed citizens of society as well as of their professional community and will be positioned for a lifetime of success.
3. Graduates will be effective communicators.

STUDENT OUTCOMES

In support of the three Program Educational Objectives, the Chemical Engineering Department has adopted the eleven Student Outcomes established in ABET Criteria 3, (1)-(7), listed below:
Students shall demonstrate:

1) an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2) an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3) an ability to communicate effectively with a range of audiences
4) an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5) an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6) an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7) an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Program Distribution Requirements for the Chemical Engineering Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7), students wishing to receive the ABET-accredited degree designated "Chemical Engineering" must satisfy the distribution requirements shown below.

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Base Science (Notes 1 and 2)	4
2. Engineering Science and Design (Notes 3 and 4)	6
3. Advanced Chemistry and Natural Science (Note 5)	5/3

NOTES:

1. Must include differential and integral calculus and differential equations.
2. Must include 3 courses in chemistry, 2 courses in physics and 1 course in biology or biochemistry.
3. Must include 1 unit of MQP, 1/3 unit of capstone design experience (e.g. CHE 4404), and at least 1/3 unit of engineering study outside the major. Courses used to satisfy this requirement must be at the 2000-level or above, with the exception of CHE 1011. Students may not count both CHE 1011 and ES 2002 as engineering electives. CS and DS courses are included in the category of engineering study.
4. Must include at least 4 units from the following list of core chemical engineering courses: CHE 2011, CHE 2012, CHE 2013, CHE 2014, ES 3004, ES 3003, ES 3002, CHE 3201, CHE 3501, CHE 4401, CHE 4402, CHE 4403, CHE 4404, CHE 4405, CHE 4410. Students may not count both CHE 4404 and CHE 4410 as core courses.
5. Advanced chemistry and natural science courses are defined as any 2000-level and above BB, CH, PH, or GE course and CH 1040. Must include 3 advanced CH courses at 2000-level or above. Up to 2/3 unit of advanced chemistry and natural science may be double counted under requirements 1 and 3.

CONCENTRATIONS FOR CHEMICAL ENGINEERING MAJORS

Chemical engineering majors may choose to focus their studies by obtaining one of the following Concentrations: Biological, Energy, Environmental, or Materials. A Concentration is not mandatory and some students will benefit from exploring a variety of areas rather than choosing to focus on one. The Concentrations require 3 units of study (potentially all of which may be double-counted towards the Chemical Engineering degree) comprised of the following: an MQP (that satisfies the Chemical Engineering degree requirement and covers a topic in the Concentration field) and 2 units from the appropriate list below. We have designed each concentration around a fundamental course offered annually in the Department (shown in bold for each concentration below) that students are encouraged to take. Students should consult their academic advisor for advice and the Chemical Engineering Department Undergraduate Committee for approval of an appropriate course of study. Appropriate experimental courses, ISUs, and other appropriate courses or projects, not on the current lists, may be applied towards a Concentration with approval from the Chemical Engineering Undergraduate Committee.

CHEMICAL ENGINEERING WITH BIOLOGICAL CONCENTRATION

Science:

BB 1035 Biotechnology*
BB 1025 Human Biology*
BB 2003 Fundamentals of Microbiology
BB 2550 Cell Biology
BB 3102 Human Anatomy & Physiology: Transport and Maintenance
BB 560 Separation of Biological Molecules
CH 4110 Protein Structure and Function
CH 4120 Lipids and Biomembrane Functions
CH 4130 Nucleic Acids and Bioinformation

Engineering Science and Design:

CHE 3201 Kinetics and Reactor Design
CHE 3301 Introduction to Biological Engineering
CHE 4402 Unit Operations Laboratory II
BME 1001 Introduction to Biomedical Engineering+
BME 2511 Introduction to Biomechanics and Biotransport
BME/ME 4504 Biomechanics
BME/ME 4606 Biofluids
BME/ME 4814 Biomaterials
CHE 521 Biochemical Engineering
BB 509 Scale-Up of Bioprocessing

*No more than one 1000-level course may be counted.

CHEMICAL ENGINEERING WITH ENERGY CONCENTRATION

Science:

CH 3510 Chemical Thermodynamics*
CH 3550 Chemical Dynamics
PH 2101 Principles of Thermodynamics*

Engineering Science and Design:

CHE 3201 Kinetics and Reactor Design
CHE 3301 Introduction to Biological Engineering
CHE 3702 Energy Challenges in the 21st Century
CHE 3722 Bioenergy
CHE 4402 Unit Operations of Chemical Engineering II
ES 3001 Introduction to Thermodynamics*
ES 3003 Heat Transfer
ES 3005 Radiation Heat Transfer Applications
ME 4710 Gas Turbines for Propulsion and Power Generation
CHE 506 Kinetics and Catalysis
CHE 507 Chemical Reactor Design
CHE 531 Fuel Cell Technology
CHE 561 Advanced Thermodynamics
FP 520 Fire Modeling
FP 521 Fire Dynamics

*Only one of the following courses may be counted: ES 3001, CH 3510, or PH 2101.

CHEMICAL ENGINEERING WITH ENVIRONMENTAL CONCENTRATION

Science:

GE 2341 Geology
BB 1002 Environmental Biology
BB 2040 Principles of Ecology

Engineering Science and Design:

CHE 3301 Introduction to Biological Engineering
CHE 3910 Chemical and Environmental Technology
CHE 3920 Air Quality Management
CHE 3201 Kinetics and Reactor Design
CHE/CE 4063 Transport and Transformations in the Environment
CHE 4402 Unit Operations Laboratory II
ES 3002 Mass Transfer
ES 2800 Environmental Impacts of Engineering Decisions
CE 3060 Water Treatment
CE 3061 Waste Water Treatment
CE 4060 Environmental Engineering Lab
CE 4061 Hydrology
CE 3059 Environmental Engineering*
CE 3070 Introduction to Urban and Environmental Planning*
CE 3074 Environmental Analysis*

*Only one of the following courses may be counted: CE 3059, CE 3070, or CE 3074.

CHEMICAL ENGINEERING WITH MATERIALS CONCENTRATION

Science:

CH 2320 Organic Chemistry II
CH 3410 Structure, Bonding, and Reactivity in Inorganic Chemistry
CH 4330 Organic Synthesis

Engineering Science and Design:

ES 2001 Introduction to Material Science
CHE 3201 Kinetics and Reactor Design
CHE 508 Catalysis and Surface Science of Materials
ME 2820 Materials Processing
ME 3801 Experimental Methods in Material Science and Engineering
ME 4813 Ceramics and Glasses for Engineering Applications
ME 4814 Biomaterials
ME 4821 Plastics
ME 4832 Corrosion and Corrosion Control
ME 4840 Physical Metallurgy
ME 4875/MFE 575 Introduction to Nanomaterials and Nanotechnology

CHEMISTRY AND BIOCHEMISTRY

A. GERICKE, HEAD; J. P. DITTAMI, ASSOCIATE HEAD

PROFESSORS: J. M. Argüello, B. Bursten, J. P. Dittami, A. Gericke, S. Scarlata
ASSOCIATE PROFESSORS: S. C. Burdette, R. Dempski, M. H. Emmert, G. Kaminski, J. C. MacDonald, A. Mattson, K. N. Wobbe
ASSISTANT PROFESSORS: J. Grimm, C. Olsen
ASSOCIATE TEACHING PROFESSORS: D. Brodeur, D. Heilman, C. Lambert, U. Kumar
ASSISTANT TEACHING PROFESSOR: A. Cooper-Morgan
EMERITUS PROFESSORS: N. Kildahl, J. Pavlik, A. Seala, S. Weininger

MISSION STATEMENT

Through dynamic and innovative classroom instruction and exciting cutting edge research programs, the Department of Chemistry and Biochemistry strives to provide students with both a broad understanding of the fundamentals of the chemical sciences and an opportunity to create new chemical and biochemical knowledge through original research. We aspire to produce graduates who will enter their scientific careers with the confidence and competence to lead the advance of chemistry and biochemistry in the 21st century.

PROGRAM EDUCATIONAL OBJECTIVES

The Department of Chemistry and Biochemistry will graduate outstanding professionals possessing fundamental knowledge of the chemical sciences. Graduates will be able to apply this knowledge to the solution of problems in chemistry and biochemistry for the advancement of knowledge in these fields and the improvement of the standard of living of all humanity.

PROGRAM OUTCOMES

Students graduating with a major in Chemistry or Biochemistry will be able to demonstrate an ability to:

- perform accurate and precise quantitative measurements
- use and understand modern instruments, particularly NMR, IR, and UV-vis spectrometers, chromatographs, electrochemical instruments, and lab computers
- keep legible and complete experimental records
- analyze data statistically and assess reliability of results
- anticipate, recognize, and respond properly to hazards of chemical manipulations
- interpret experimental results and draw reasonable conclusions
- plan and execute experiments through use of the literature
- design experiments
- communicate effectively through oral and written reports
- critically assess their work for reasonableness and self-consistency
- adhere to high ethical standards
- learn independently

BIOCHEMISTRY

Program Distribution Requirements for the Biochemistry Major

In addition to the WPI requirements applicable to all students (see page 7), students wishing to graduate with a degree in biochemistry must meet the distribution requirements detailed below.

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Physics (Note 1).	2
2. Chemistry and Biochemistry (Note 2).	4 1/3
3. Biology (Note 3).	1 1/3
4. Chemistry and Biochemistry/ Biology Laboratory (Note 4).	1
5. Other Natural or Computer Science (Note 5).	1/3
6. MQP	1

NOTES:

1. The mathematics in MA 1021-MA 1024 or the equivalent is recommended. The physics in PH 1110-PH 1120 or equivalent is recommended.
2. These 4 1/3 units must include one unit of organic, 1 1/3 units of biochemistry, and 1/3 unit each of physical (3000 level or higher) and inorganic chemistry (3000 level or higher).
3. These 1 1/3 units must include 1/3 unit of cell biology, 1/3 unit of genetics, and 1/3 unit of advanced work (3000 level or higher).
4. This unit must include a minimum of 2/3 units of Chemistry and Biochemistry labs, of which 1/3 unit must be either CH 4150 or CH 4170. The remaining 1/3 unit may come from BB or CBC labs. However, counting both CH 4170 and BB 3512 is not allowed.
5. Any course in the natural sciences (not used to satisfy another requirement) or in computer science may be used to satisfy this requirement.

RECOMMENDATIONS FOR STUDENTS

A typical Biochemistry curriculum is given below.

Premedical students should take three terms of Physics, as well as one of the Organic Chemistry Laboratories (CH 2360 or CH 2660), by the end of their third year. BB 1035 is recommended as the initial course for students who need to strengthen their background in biology. Note that a total of one unit designated Elective in the table must be in Biology.

Students should take 1/3 unit of advanced Biology laboratory (BB 3512, 3518, 3519, 3520 are recommended) at their discretion as to the term; however, this should preferably be done before the MQP is commenced.

Recommended Biochemistry Program

Year	Term A	Term B	Term C	Term D
First	CH 1010 BB 2550 MA	CH 1020 HU MA	CH 1030 BB 2920 MA	CH 1040 HU MA
Second	CH 3510 CH 2640 HU	CH 2310 SS HU	CH 2320 HU PH	CH 2330 HU PH
Third	CH 4110 BB Lab SS	CH 4120 CH 4150 IQP	CH 4130 CH 3410 IQP	CH 4170 CH 4140 IQP
Fourth	Elective MQP Elective	Elective MQP Elective	CH 4160 MQP Elective	CH 4190 MQP Elective

CHEMISTRY

Program Distribution Requirements for the Chemistry Major

In addition to the WPI requirements applicable to all students (see page 7), students wishing to graduate with a degree in chemistry must meet the distribution requirements detailed below.

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Physics (Note 1).	2 1/3
2. Chemistry (Notes 2, 3).	4
3. Additional Science/Engineering (Notes 3, 4).	3 2/3

NOTES:

1. Must include differential and integral calculus and at least 2/3 units of physics.
2. Must be above the level of general chemistry (2000 level or higher). These 4 units must include courses in experimental chemistry (either 4/3 unit or 3/3 unit), inorganic chemistry (1/3 unit), organic chemistry (3/3 unit), physical chemistry (3/3 unit), and biochemistry (either 1/3 unit or 2/3 unit, depending on the number of experimental chemistry courses taken). At least 2/3 units must be at or higher than the 4000 level.
3. Students cannot receive credit for both CH 2360 and CH 2660.
4. Distributed among the MQP, the natural and physical sciences, computer science, mathematics, and engineering (and including general chemistry, CH 1010-1040).

RECOMMENDATIONS FOR STUDENTS

Chemistry utilizes many of the concepts of physics and the tools of mathematics. Thus students should acquire a background in these subjects early in their programs. The material addressed in MA 1021 through MA 1024 is recommended for all chemistry majors. Students will also benefit from knowledge of differential equations, as discussed in MA 2051. Physics background should include mechanics, and electricity and magnetism. Either the PH 1110-1120 or the PH 1111-1121 sequence is recommended. Students seeking more depth in physics are advised to pursue PH 1130 and PH 1140.

Students seeking ACS certification (see below) should plan to study calculus through introductory multivariable calculus (MA 1021-1024), differential equations (MA 2051) and linear algebra (MA 2071), and should take a minimum of two courses in physics (for example, PH 1111 and PH 1121).

AMERICAN CHEMICAL SOCIETY APPROVAL AND CERTIFICATION

The Department of Chemistry and Biochemistry has an American Chemical Society (ACS) approved program. Thus graduates who complete programs satisfying the ACS recommendations have their degrees certified to the society by the department. Accordingly, students can earn an "ACS-Certified Degree in Chemistry" or an "ACS-Certified Degree in Chemistry with a Biochemistry Option."

ACS-Certified graduates are eligible for immediate membership in the ACS and thus are able to secure the benefits of membership, which include helpful services such as finding employment.

ACS-CERTIFIED DEGREE IN CHEMISTRY

The following sequence of courses, recommended to provide fundamental background in chemistry, will result in an ACS-certified degree in chemistry. Specialization in particular areas of interest is best accomplished via additional courses and projects, generally taken in the third and fourth years.

Recommended CBC Courses for an ACS-Certified Degree in Chemistry

Year	Term A	Term B	Term C	Term D
First	CH 1010	CH 1020	CH 1030	CH 1040
Second	CH 2640 (lab) CH 3510 (phys)	CH 2650 (lab) CH 2310 (org)	CH 2660 (lab) CH 2320 (org)	CH 2670 (lab) CH 2330 (org)
Third		CH 3550 (phys)	CH 3410 (inorg) CH 3530 (phys)	
Fourth	CH 4110 (bioch)			CH 4420 (inorg)

ACS-CERTIFIED DEGREE IN CHEMISTRY WITH A BIOCHEMISTRY OPTION

Students seeking the ACS-Certified Degree with Biochemistry Option must complete the following work in addition to those requirements noted above for an ACS-Certified Degree in Chemistry.

- 1/3 unit of biology which contains cell biology, microbiology or genetics.
- 2/3 unit of biochemistry that has organic chemistry as a prerequisite.
- 1/3 unit of a laboratory in biochemical methods.
- Research in biochemistry culminating in a comprehensive written report is highly recommended.

CONCENTRATION IN MEDICINAL CHEMISTRY

Medicinal Chemistry is the application of principles of biology and chemistry to the rational design and synthesis of new drugs for treatment of disease. A medicinal chemist applies knowledge of chemistry, biochemistry and physiology to generate solutions to health-related problems.

A concentration in medicinal chemistry is excellent preparation for students interested in entering health related professions, such as the pharmaceutical industry, upon graduation. Possible employment positions are numerous and expected to increase in the future.

COURSE REQUIREMENTS

In order to be eligible to receive the Medicinal Chemistry designation on their transcripts, chemistry majors need to satisfy the following course requirements:

Three biomedically oriented courses selected from the following list must be included in the distribution requirements:

- CH 4110 Protein Structure and Function
- CH 4120 Lipids and Biomembrane Functions
- CH 4130 Nucleic Acids and Bioinformation
- CH 4150 Enzymology and Protein Characterization Laboratory
- CH 4170 Experimental Genetic Engineering

Three courses oriented toward structure, synthesis, or mechanisms selected from the following list must be included in the distribution requirements. (All graduate courses in chemistry are open to undergraduates.)

- CH 4330 Organic Synthesis
- CH 516 Chemical Spectroscopy
- CH 536 Theory and Applications of NMR Spectroscopy
- CH 538 Medicinal Chemistry
- CH 554 Molecular Modeling

In addition to the above course requirements, chemistry majors must complete an MQP in the medicinal chemistry area, approved by the Program Coordinator. Examples of available projects are:

- Synthesis of huperzine analogs. New acetylcholinesterase inhibitors for treatment of Alzheimer's.
- Synthesis of opiate analogs.
- Computer simulations of small molecules and their interactions with proteins.

PROJECT ACTIVITY

A student undertaking a Major Qualifying Project in chemistry and biochemistry chooses a faculty advisor in the department with whom to work. This choice is normally made because the student is interested in the research program directed by the faculty member, and wants to become a part of this activity. The student is given a research problem to work on for a minimum of 20 hours a week for 3 terms. Although most MQP projects in chemistry and biochemistry are individual student efforts, team projects involving up to 3 students are occasionally available, depending on the faculty member concerned. The project culminates in a formal written MQP report and a poster session presentation to the department faculty and students. MQP projects in chemistry and biochemistry require a substantial effort from the student in both the laboratory and writing phases. Many projects result in professional publications and/or presentations at professional meetings. The department offers a variety of areas of specialization (see AREAS OF SPECIALIZATION IN CHEMISTRY AND BIOCHEMISTRY below) in which Major Qualifying Projects may be carried out.

Some students, particularly those in biochemistry, choose to do their MQPs at off-campus laboratories. Biochemistry projects have recently been completed at the University of Massachusetts Medical Center and Tufts University School of Veterinary Medicine.

AREAS OF SPECIALIZATION IN CHEMISTRY AND BIOCHEMISTRY

Computational Chemistry and Molecular Modeling
Gene Regulation
Homogeneous Catalysis
Ion Transport
Materials
Medicinal Chemistry
Membrane Proteins
Membrane Signaling Processes
Molecular Spectroscopy
Nanoscale Design
Natural Products Synthesis
Animal-Virus Biochemistry
Photochemistry
Photophysics
Sensors
Supramolecular Chemistry

MINOR IN BIOCHEMISTRY

A biochemistry minor allows students to develop real depth of understanding in biochemistry. The minor can include laboratory work, or be entirely classroom based. As biochemistry is a science that utilizes fundamentals from both chemistry and biology, courses from both areas are included. Some knowledge of organic chemistry is required to fully understand biochemistry.

Two units of study are required for the biochemistry minor as follows (note that in accordance with Institutional rules, one full unit, including the capstone, must be independent of distribution requirements for the major). Courses may count in only one area.

1. 1/3 unit of organic chemistry selected from
   CH 2320
   CH 2330
   CH 2360
2. 1/3 unit of biology focused on cellular or subcellular biology. Acceptable courses include
   BB 2550 BB 3620
   BB 2920 BB 3920
   BB 3080
3. At least 3/3 unit of biochemistry selected from
   CH 4110 CH 4150
   CH 4120 CH 4170
   CH 4130
4. Capstone to be selected from
   CH 4150 CH 4170
   CH 4160 CH 4190

Majors in chemistry may not receive a biochemistry minor.

MINOR IN CHEMISTRY

The Minor in Chemistry is flexible and allows a student to design a minor with the balance between depth and breadth that is appropriate for the student's specific educational and professional objectives. of the two units of required study, one unit must be at an advanced level (3000/4000), including a 4000 level capstone course. WPI policy for double counting courses to satisfy the requirements for a minor can be found in the Undergraduate Catalog.

REQUIREMENTS (Note 1)	UNITS
1000 level CH course	1/3
2000 level CH courses (Note 2)	2/3
3000/4000 level CH courses	2/3
4000 level CH courses (capstone)	1/3

NOTES

1. A higher level CH course can be used to satisfy the requirement for a lower level course e.g. 2000 for 1000, 3000 /4000 for 2000 etc.
2. Selected from CH2310, CH2320, and CH2330.

Two examples of sequences that satisfy the requirements for a CH minor:

CH Minor with Breadth	CH Minor with Depth in Physical Chemistry
CH 1020 Chemical Reactions	CH 1020 Chemical Reactions
CH 2310 Organic Chemistry I	CH 3510 Chemical Thermodynamics
CH 2320 Organic Chemistry II	CH 3530 Quantum Chemistry
CH 3510 Chemical Thermodynamics	CH 3550 Chemical Dynamics
CH 3410 Structure, Bonding, and Reactivity in Inorganic Chemistry	CH 3410 Structure, Bonding, and Reactivity in Inorganic Chemistry
CH 4110 Protein Structure and Function	CH 4520 Chemical Statistical Mechanics

Many other sequences are possible.

CIVIL AND ENVIRONMENTAL ENGINEERING

C. M. EGGLESTON, HEAD; M. TAO, ASSOCIATE HEAD

PROFESSORS: C. M. Eggleston, T. El-Korchi, R. Mallick, H. Walker
ASSOCIATE PROFESSORS: L. D. Albano, J. Bergendahl, J. Dudle
P. P. Mathisen, N. Rahbar, A. Sakulich, G. F. Salazar, M. Tao, Van Dessel
ASSISTANT PROFESSORS: S. Liu,
INSTRUCTOR: S. LePage
ASSISTANT TEACHING PROFESSORS: L. Abu-Lail, M. Farzinmoghadam, D. Rosbach
EMERITUS PROFESSORS: F. DeFalco, R. Fitzgerald, J. C. O'Shaughnessy, R. Pietroforte
ASSOCIATED FACULTY: T. Camesano (CHE), S. Kmiotek (CHE)

MISSION STATEMENT

The Civil Engineering program at WPI prepares graduates for careers in civil engineering, emphasizing professional practice, civic contributions, and leadership, sustained by active life-long learning. The curriculum combines a project based learning environment with a broad background in the fundamental principles of civil engineering. Students have the flexibility to explore various civil engineering disciplines and career opportunities.

PROGRAM EDUCATIONAL OBJECTIVES

Graduates a few years out of the Civil and Environmental Engineering Undergraduate Program should:

1. be global citizens and stewards for the planet with an appreciation for the interrelationships between basic knowledge, technology, and society, while solving the challenges facing civil engineers in the 21st century.
2. be able to apply the fundamental principles of mathematics, science and engineering to analyze and solve problems and to produce creative sustainable design.
3. have the ability to engage in life-long learning, enhance their technical skills through graduate studies and continuing education, and through relevant experience.
4. exhibit leadership in the civil engineering profession, be engaged in professional societies, demonstrate understanding of ethical responsibility, and have a professional demeanor necessary for a successful civil engineering career.

STUDENT OUTCOMES

The Student Outcomes for the Bachelor degree in Civil Engineering are that all graduates will attain:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Program Distribution Requirements for the Civil Engineering Major

The normal period of undergraduate residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7), students wishing to receive the ABET accredited degree designated "Civil Engineering" must satisfy certain distribution units of study in the areas of mathematics, basic science, and engineering science and design as follows:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Basic Science (Notes 1,2).	4
2. Engineering Science and Design (including the MQP) (Note 3,4,5,6).	6

NOTES:

1. Mathematics must include differential and integral calculus, differential equations, and probability and statistics.
2. Must include at least one course in physics, two courses in chemistry, and one course in an additional science area.
3. A minimum of 4 units of work must be within the Civil Engineering area. All CE courses including the MQP, ES 2503, ES 2800, and ES 3004 are acceptable within the Civil Engineering area.
4. The curriculum must include at least one engineering science course outside the major discipline area. Courses acceptable to satisfy the requirement of outside-of-discipline course are those taught in other engineering departments. The course must be 2000-level or above and cannot include ES 2501, ES 2502, ES 2503, ES 2800, and ES 3004.
5. All students are required to include an appropriate laboratory experience as part of their overall program. This experience can be met by the completion of two undergraduate CE lab courses, selected from among the following: CE 2020, CE 3024, CE 3026, CE 4054, and CE 4060. Alternately, an appropriate laboratory experience could also be accomplished by a student through careful planning of course, project and laboratory work and approval by petition through the Department Program Review Committee.
6. Must include 1/3 unit of Capstone Design Experience, and 4/3 units from the following list of Civil Engineering courses: CE 2020, CE 3010, CE 3020, CE 3041, CE 3050, CE 3059, and CE 3062.

PROGRAM DEVELOPMENT AND COURSE SELECTION

Students must meet distribution requirements for the Civil Engineering major; however, no unique courses are specifically required. Students should consult with their academic advisor to develop a program of study that meets WPI and ABET requirements. In addition, students should achieve breadth across the civil engineering discipline by taking courses in at least four subareas, depth within subareas of interest, and an understanding of the civil engineering profession. Lastly, a concentration in the environmental subarea is available. The program chart on page 59 can aid students in developing their plan of study.

SUBAREAS OF CIVIL ENGINEERING

Civil and environmental engineers plan, design, build and maintain the facilities that are paramount to modern society - facilities that provide for a high quality of life. These include buildings, transportation systems, waterways, and water and wastewater treatment systems, to name a few. Today, these facilities are designed using modern information systems and the principles of sustainability. Several subareas of civil and environmental engineering are available for study. Students are encouraged to take courses in multiple areas and develop an understanding for the interrelationships between these subareas that are involved in most civil engineering problems.

STRUCTURAL AND GEOTECHNICAL ENGINEERING

(L. Albano, T. El-Korchi, R. Mallick, N. Rahbar, A. Sakulich, M. Tao)

The practice of structural engineering involves the analysis and design of buildings, bridges, roads, and other components of our infrastructure. An understanding of mechanics and the engineering properties of construction materials serves as a foundation for study in this area. Geotechnical engineering focuses on the engineering behavior of earth materials. The design, analysis and construction of subsurface facilities includes a broad array of applications - including building foundations, pavement subgrades, tunnels, dams, landfills, and groundwater development.

ENVIRONMENTAL ENGINEERING

(J. Bergendahl, J. Dudle, C. M. Eggleston, S. LePage, P. Mathisen, H. Walker)

Environmental engineering involves protection of natural ecosystems as well as protection of public health. The practicing environmental engineer is concerned with planning, design, construction, operation and regulation of water quality control systems related to water supply and treatment, wastewater collection and treatment, and water resources protection. The environmental engineer is also concerned with hazardous waste remediation, pollutant migration and modeling, solid waste management, public health, radiological health, and air pollution control.

TRANSPORTATION ENGINEERING

(T. El-Korchi, S. LePage, R. Mallick, M. Tao)

Transportation engineers focus on the safe and efficient movement of people and goods. In particular, transportation engineers plan, design, construct, and operate highways and other facilities, such as transit systems, railways, and airports. The transportation infrastructure in the U.S. plays an important role in commerce, and the development of systems to carry large volumes of traffic safely and securely is important. Thus, the transportation engineer is concerned with roadway development, pavement engineering, drainage systems, traffic engineering, roadside safety, and travel demand modeling.

URBAN AND ENVIRONMENTAL PLANNING

(S. LePage, P. Mathisen)

The Urban and Environmental Planning area involves evaluating relationships between community development and both the natural and built environment. Planners seek to improve the quality of life in communities, with particular emphasis on environmentally conscious and sustainable solutions. Through the analysis and presentation of relevant data, planners inform and guide the public decision-making process while balancing economic, political, environmental, and social concerns. By exploring methods in community master planning, environmental impact analysis, growth management, and land use regulation, students can develop a comprehensive understanding of the framework within which civil engineers address urban and environmental planning problems.

CONSTRUCTION ENGINEERING AND PROJECT MANAGEMENT

(L. Albano, G. Salazar)

The construction engineering and project management subarea is directed to students whose interests lie in the design and construction engineering process but who are also concerned with engineering economics, social science, management, business, labor and legal relations, and the interaction of governmental and private interests as they relate to major construction projects. Engineers in this subarea plan, estimate, schedule and manage the construction of engineered facilities using modern tools - including information technologies and control systems.

ENVIRONMENTAL CONCENTRATION

Civil Engineering majors may choose to focus their studies by obtaining an Environmental concentration. An Environmental concentration in the CEE Department focuses on the planning, design, construction, operation and regulation of water quality control systems related to water supply and waste treatment. Additional areas of focus include hydrology, hydraulics, water resources, solid and hazardous waste management, waste minimization, public health and air pollution control.

Students electing to pursue the Environmental concentration follow a general curriculum in Civil Engineering, with emphasis on the environmental engineering subarea. Such preparation leads to an ABET accredited degree, and is an excellent start for entry-level professional placement or graduate study in environmental engineering.

The Environmental concentration is earned by completing six courses from the following list (or alternate courses through petition) plus an MQP in the environmental area. Typical MQPs include analysis and design of innovative water treatment, water quality monitoring and pollutant control, water resources analysis and groundwater studies, innovative solid waste solutions, and air pollution control.

CE 3059	Environmental Engineering
CE 3060	Water Treatment
CE 3061	Wastewater Treatment
CE 3062	Hydraulics
CE 3070	Urban and Environmental Planning
CE 3074	Environmental Analysis
CE 4060	Environmental Engineering Laboratory
CE 4061	Hydrology
CE/CHE 4063	Transport and Transformations in the Environment
CE 4071	Land Use Development & Controls
CE 4600	Hazardous and Industrial Waste Management
CHE 3201	Kinetics and Reactor Design

PROJECTS

A great variety of projects are available to civil and environmental engineering students. Students may select project topics which are related to their subarea of emphasis, or may develop interdisciplinary projects that incorporate multiple subareas. Projects exemplify the type of work students will encounter in

CIVIL ENGINEERING PROGRAM CHART

This chart summarizes course and scheduling recommendations

First Year/ Sohpomore	**MATHEMATICS AND SCIENCE (4 units minimum required)**							
	Differential and Integral Calculus	Differential Equations	Statistics	Probability	Chemistry	Physics	Additional Science	Math/Science Elective
	4/3 unit	1/3 unit	1/3 unit	1/3 unit	2/3 unit	1/3 unit	1/3 unit	1/3 unit
	MA 1021 (or 1020) MA 1022 MA 1023 MA 1024	MA 2051	MA 261	MA 2621	CH 1010 CH1020	PH 1110 (or 1111)	GE or BB	MA, CH, PH, GE, or BB
	HUMANITIES AND ARTS (2 units minimum required)							
	SOCIAL SCIENCE (2/3 units minimum required)							
Junior	**IQP (1 unit minimum required)**							
Anytime	**PHYSICAL EDUCATION (2 units minimum required)**							

	ENGINEERING SCIENCE AND DESIGN (6 units minimum required; 4 units minimum required in Civil Engineering)							
First Year/ Sophomore	Engineering Science	CE 1030, CE 2000, CE 2001, CE 2002, CE 2020, ES 2503, ES 2800, ES 3004						
Junior/ Senior	Computer Applications	CE 3030, CE 3031						
	Outside of CE	2001, ED3001, ECE 2010, or other 2000-level or above engineering course						
	Civil Engineering	Subareas	Structural	Geotechnical	Environmental and Hydraulics	Urban and Environmental Planning	Transportation	Construction Engineering and Project Management
		Courses	CE 3010 CE 3006 CE 3008 CE 4007 CE 4017	CE 3041 CE 3044	CE 3059 CE 3060 CE 3061 CE 3062 CE 4061 CE/CH 4063 CE 4600	CE 3070 CE 3074 CE 4071	CE 3050 CE 3051	CD 3020 CD 3022 CD 3025
		Labs	CE 3026		CE 4060		CE 4054	CE 3024
		MQP	Project in areas of interest, including capstone design					
Anytime	**ELECTIVES (1 unit)**							

their post-graduate pursuits. Project activities can include a combination of design, construction planning, sponsored research, laboratory investigations, field work, and internship activities with governmental agencies and private industry. Students should plan their Major Qualifying Project activity during the junior year, in consultation with a faculty advisor. The MQP should include analysis of a comprehensive civil engineering problem, consideration of alternative solutions, and optimization of a solution. A major objective of the MQP is the development of sound engineering judgment, incorporating engineering economics and social factors into problem solving.

Each civil engineering student must complete a capstone design experience which draws on past course work, involves significant engineering design, and relates to the practice of civil engineering. Normally, this is accomplished as part of the MQP. At the time of registration for the MQP, the project advisor indicates whether the project meets the capstone requirement. If not, the advisor will provide an additional 1/3 unit of capstone design (not MQP) work to meet the requirement. Alternatively, another MQP which meets the requirement could be selected.

FUNDAMENTALS OF ENGINEERING EXAM

The first step to becoming a licensed professional engineer is passing the Fundamentals of Engineering (FE) exam. Licensure is used to ensure public safety by requiring practicing consultants to demonstrate their qualifications based on education, experience, and examinations, including the FE exam. Engineers who attain licensure enjoy career benefits that allow them to offer consulting services and rise to positions of responsibility. All Civil Engineering majors are strongly encouraged to take the FE exam during their senior year. The exam is offered year-round.

COMBINED BACHELOR/MASTER'S PROGRAM

Continued studies beyond the bachelor's degree are valuable for career advancement and professional engineering licensure. Combined Bachelor/Master's degree programs offer the advantage of double-counting up to 12 credits, including up to six credits of advanced coursework (4000-level) at the undergraduate level, for both the Bachelor's and Master's degree requirements. Specific CEE requirements and more information can be obtained at the Civil and Environmental Engineering Department office. Programs leading to the Master of Science and Master of Engineering are available. Students should consult with their academic advisor to discuss program options, admission requirements, and course planning.

COMPUTER SCIENCE

C. E. WILLS, HEAD
C. RUIZ, ASSOCIATE HEAD
PROFESSORS: E. Agu, M. Claypool, D. J. Dougherty, M. A. Gennert, N. Heffernan, E. A. Rundensteiner, G. N. Sarkozy, C. E. Wills, J. Xiao
ASSOCIATE PROFESSORS: J. E. Beck, M. Y. Eltabakh, G. T. Heineman, D. Korkin, C. Ruiz, C. A. Shue
ASSISTANT PROFESSORS: B. Calli, L. De Carli, L. Fichera, T. Guo, L. T. Harrison, X. Kong, K. Lee, Y. Li, C. Pinciroli, D. Reichman, C. Roberts, G. Smith, E. Solovey, R. J. Walls, J. R. Whitehill, A. Yousefi
RESEARCH PROFESSORS: J. Guttman, C. L. Sidner
ASSOCIATE TEACHING PROFESSOR: R. Neamtu
ASSISTANT TEACHING PROFESSORS: M. Engling, T. Smith, J. Weinstock, W. Wong
INSTRUCTOR: J. M. Cuneo
PROFESSORS EMERITUS: D. C. Brown, D. Finkel, M. Hofri, R. E. Kinicki, K. A. Lemone, S. M. Selkow
ASSOCIATED FACULTY: S. Barton (HU), A. Lammert (BME), W. Martin (MA), W. Michalson (ECE), C. Ngan (DS), R. Paffenroth (MA), K. Pahlavan (ECE), C. Putnam (RBE), H. Zhang (BME)

MISSION STATEMENT

The mission of the Computer Science Department at WPI is to provide outstanding education to its undergraduate and graduate students in accordance with the principles of the WPI mission, to advance scholarship in key domains of the computing sciences, and to engage in activities that improve the welfare of society and enhance the reputation of WPI. The Department aims to maintain an environment that promotes innovative thinking, values mutual respect and diversity, encourages and supports scholarship, instills ethical behavior, and engenders life-long learning.

PROGRAM EDUCATIONAL OBJECTIVES

In support of its goals and mission, the WPI Computer Science undergraduate program's educational objectives are to graduate students who will

- achieve professional success due to their mastery of Computer Science theory and practice;
- become leaders in business, academia, and society due to a broad preparation in mathematics, science & engineering, communication, teamwork, and social issues;
- pursue lifelong learning and continuing professional development;
- use their understanding of the impact of technology on society for the benefit of humankind.

PROGRAM OUTCOMES

Based on the educational objectives, the specific educational outcomes for the WPI Computer Science undergraduate program are that by the time of graduation CS majors will have achieved

1. an understanding of programming language concepts;
2. knowledge of computer organization;
3. an ability to analyze computational systems;

4. knowledge of computer operating systems;
5. an understanding of the foundations of computer science;
6. an understanding of software engineering principles and the ability to apply them to software design;
7. an understanding of human-computer interaction;
8. completion of a large software project;
9. knowledge of advanced computer science topics;
10. an understanding of mathematics appropriate for computer science;
11. knowledge of probability and statistics;
12. an understanding of scientific principles;
13. an ability to design experiments and interpret experimental data;
14. an ability to undertake independent learning;
15. an ability to locate and use technical information from multiple sources;
16. an understanding of professional ethics;
17. an understanding of the links between technology and society;
18. an ability to participate effectively in a class or project team;
19. an ability to communicate effectively in speech;
20. an ability to communicate effectively in writing.

Program Distribution Requirements for the Computer Science Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7), the program distribution requirements for the Computer Science major include computer science, mathematics, and basic science and/or engineering science as follows:

COMPUTER SCIENCE	MINIMUM UNITS
1. Computer Science (including the MQP) (Notes 1, 2).	6
2. Mathematics (Notes 2, 3, 5).	7/3
3. Basic Science and/or Engineering Science (Notes 2, 4).	5/3

NOTES:

1. a. Only CS 1101, CS 1102 and computer science courses at the 2000-level or higher will count towards the computer science requirement. CS 2119 will not count towards the computer science requirement.

   b. Must include at least 1/3 unit from each of the following areas: Systems (CS 3013, CS 4513, CS 4515, CS 4516), Theory and Languages (CS 3133, CS 4120, CS 4123, CS 4533, CS 4536), Design (CS 3041, CS 3431, CS 3733, CS 4233), and Social Implications of Computing (CS3043, GOV/ID 2314, GOV/ID 2315, IMGD 2000, IMGD 2001, RBE 3100). (If GOV/ID 2314, GOV/ID 2315, IMGD 2000, IMGD 2001 or RBE 3100 is used to satisfy this requirement, it does not count as part of the 6 units of CS.)

   c. At least 5/3 units of the Computer Science requirement must consist of 4000-level or graduate CS courses, except for CS 5007.

   d. Any of the following graduate courses (when used as described in Note 1c) can be used to satisfy the undergraduate Theory and Languages area requirement: CS 5003, CS 5084, CS 503, CS 536, CS 544, or CS 584. Any of the following graduate courses (when used as stated in Note 1c) can be used to satisfy the undergraduate Systems area requirement: CS 502, CS 533, or CS 535.
   Any of the following graduate courses (when used as stated in Note 1c) can be used to satisfy the undergraduate Design area requirement: CS 509, CS 542, CS 546, CS 561, or CS 562.

   e. Only one of CS 1101 and CS 1102 may count towards the computer science requirement. Only one of CS 2301 and CS 2303 may count towards the computer science requirement. Only one of CS 2102, CS 210X, and CS 2103 may count towards the computer science requirement.
2. A cross-listed course may be counted toward only one of areas 1, 2, 3, above.
3. Must include at least 1/3 unit from each of the following areas: Probability (MA 2621, MA 2631) and Statistics (MA 2611, MA 2612).
4. Courses satisfying the science requirement must come from the BB, BME, CE, CH, CHE, ECE, ES, GE, ME, PH, or RBE disciplines. At least three courses must come from BB, CH, GE, or PH, where at least two courses are from one of these disciplines.
5. At most four 1000-level Mathematics courses may be counted towards this requirement.

ADDITIONAL ADVICE

For additional advice about course selections, students should consult with their academic advisor or the Computer Science Department Web site (http://www.cs.wpi.edu/Undergraduate/).

INDEPENDENT STUDY

Independent study and project work provide the opportunity for students, working under the direction of faculty members, to study or conduct research in an area not covered in courses or in which the students require a greater depth of knowledge. The background required of a student for independent study work depends on the particular area of study or research.

PROJECT OPPORTUNITIES

Off-campus major qualifying projects are available at several project centers including the Budapest Project Center, the Lincoln Laboratory Project Center, the Japan Project Center, the Microsoft-Cambridge Project Center, and the Wall Street Project Center.

Projects are also available on campus, both to support the on-going research activities of the faculty and to expand and improve the applications of computers for service, education, and administration.

Additionally, the department supports IQPs in a number of areas.

ADVANCED PLACEMENT

Advanced placement in computer science can be earned for the “Computer Science AP A” exam. Credit for CS 1000 is granted for scoring a “4” or “5” on the CS AP A exam. No credit will be granted for “Computer Science AP Principles” exam.

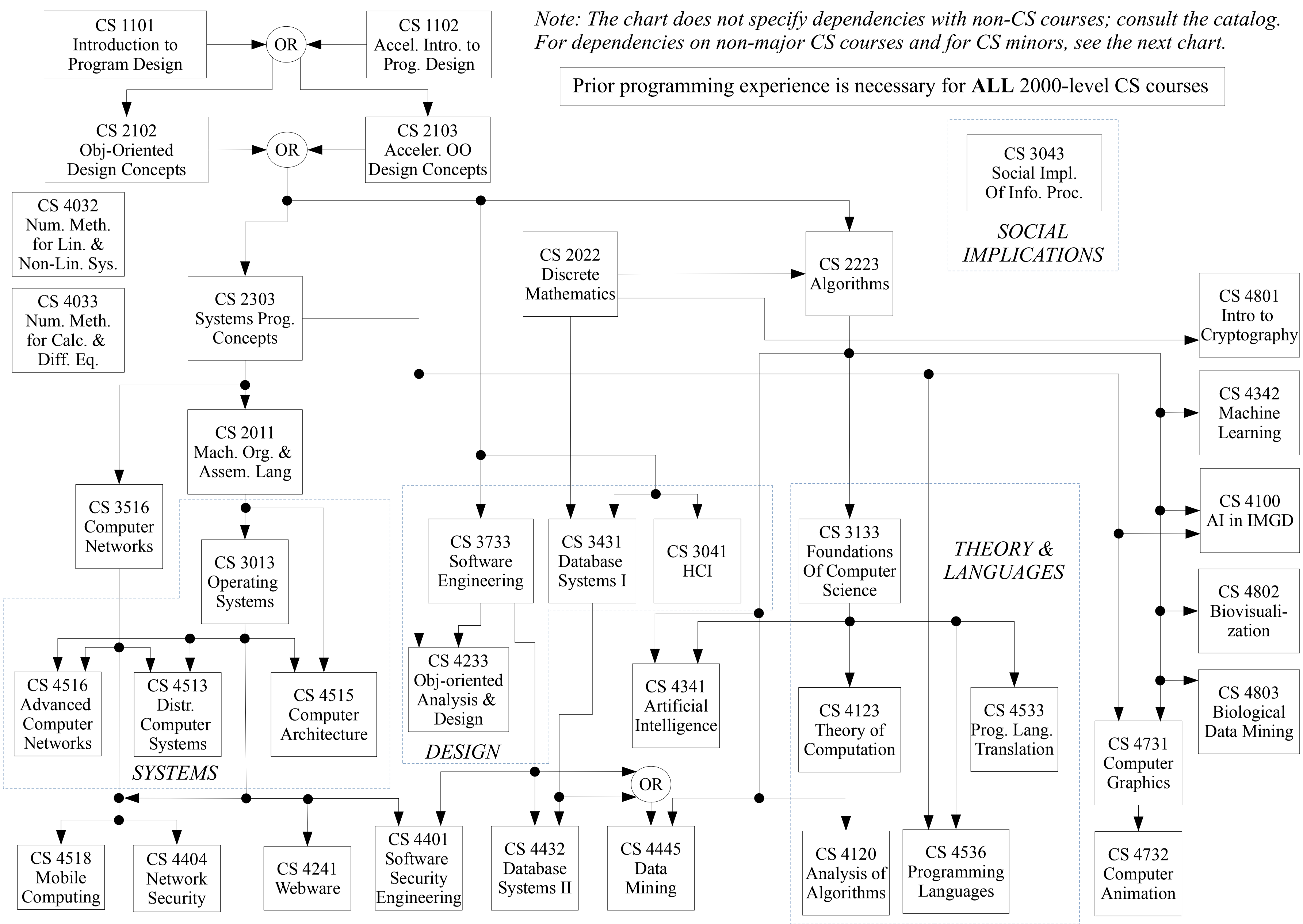
The Computer Science department advises CS Majors who earn a “4” or a “5” on the CS AP A exam to enroll in CS 1102 (Accelerated Introduction to Program Design). Students who wish to pursue a CS Minor after earning a “4” or a “5” on the CS AP A exam may consider enrolling in CS 2119 (Application Building with Object-Oriented Concepts) or CS 2301 (Systems Programming for Non-Majors).

Students who took CS AP Principles exam and have substantial programming experience should consult with the CS course instructors as to which course to take.

COMPUTER SCIENCE COURSES FOR MAJORS FLOW CHART

Note: The chart does not specify dependencies with non-CS courses; consult the catalog. For dependencies on non-major CS courses and for CS minors, see the next chart.

Prior programming experience is necessary for **ALL** 2000-level CS courses



MINOR IN COMPUTER SCIENCE

The Minor in Computer Science will consist of 2 units from Computer Science, with no more than one course at the 1000-level. The 2 units must include at least 1/3 unit CS at the 3000-level or above; however, CS 3043, CS 4032, and CS 4033 cannot be used for a CS minor. Alternatively, 1/3 unit of another activity, for example an ISU that has been validated by the CS faculty instructor as a capstone, can substitute for this requirement.

The Computer Science Department has an advisor for CS Minors, who can be reached at minoradvisor@cs.wpi.edu. Students are required to consult with the CS Minor Advisor before declaring the CS Minor. Majors in Computer Science do not qualify for a Minor in Computer Science. Students should review the Operational Rules of the Minor at WPI to avoid problems with double counting CS courses.

For general policy on the Minor, see the description on page 11.

COMPUTER SCIENCE CONCENTRATIONS

Students pursuing the CS major may, at their option, choose to focus in the following topic of concentration:

- Cyber Security

Cyber Security Concentration

Students taking the Cyber Security Concentration must:

1. Satisfy 2/3 units in core Cyber Security classes from:
   a. Software Security Engineering (CS 4401)
   b. Tools and Techniques in Computer Network Security (CS 4404)
   c. Introduction to Cryptography and Communication Security (CS 4801/ECE 4802)
   d. Other Cyber Security-specific courses subject to program approval

COMPUTER SCIENCE PROGRAM CHART

COMPUTER SCIENCE
Minimum 18/3

CORE COURSES
CS 1101 or CS 1102, CS 2011, CS 2022, CS 2102, CS 2223, CS 2303, CS 3013, CS 3041, CS 3043, CS 3133, CS 3733
Note: Not all of the Core Courses are required for the BS degree; see the program distribution requirements

SYSTEMS —Minimum 1/3
CS 3013, CS 4513, CS 4515, CS 4516

THEORY AND LANGUAGE—Minimum 1/3
CS 3133, CS 4120. CS 4123, CS 4533, CS 4536

DESIGN—Minimum 1/3
CS 3041, CS 3431, CS 3733, CS 4233

SOCIAL IMPLICATIONS—Minimum 1/3
CS 3043, GOV/ID 2314, GOV/ID 2315, IMGD 2000, IMGD 2001, RBE 3100
CS 3043 counts toward the 18/3 CS units required for major

ADVANCED LEVEL COURSES—Minimum 5/3

COMPUTER SCIENCE MQP—Minimum 3/3

SCIENCE
Minimum 5/3
Any BB, BME, CE, CH, CHE, ECE, ES, GE, ME, PH, or RBE courses.
At least three courses must come from BB, CH, GE, or PH, where at least two courses are from one of these disciplines.

MATHEMATICS
Minimum 7/3
At most four 1000-level Mathematics courses.
May include CS 2022 , CS 4032, or CS 4033 if not used to satisfy the CS requirements.

STATISTICS—Minimum 1/3
MA 2611, MA 2612

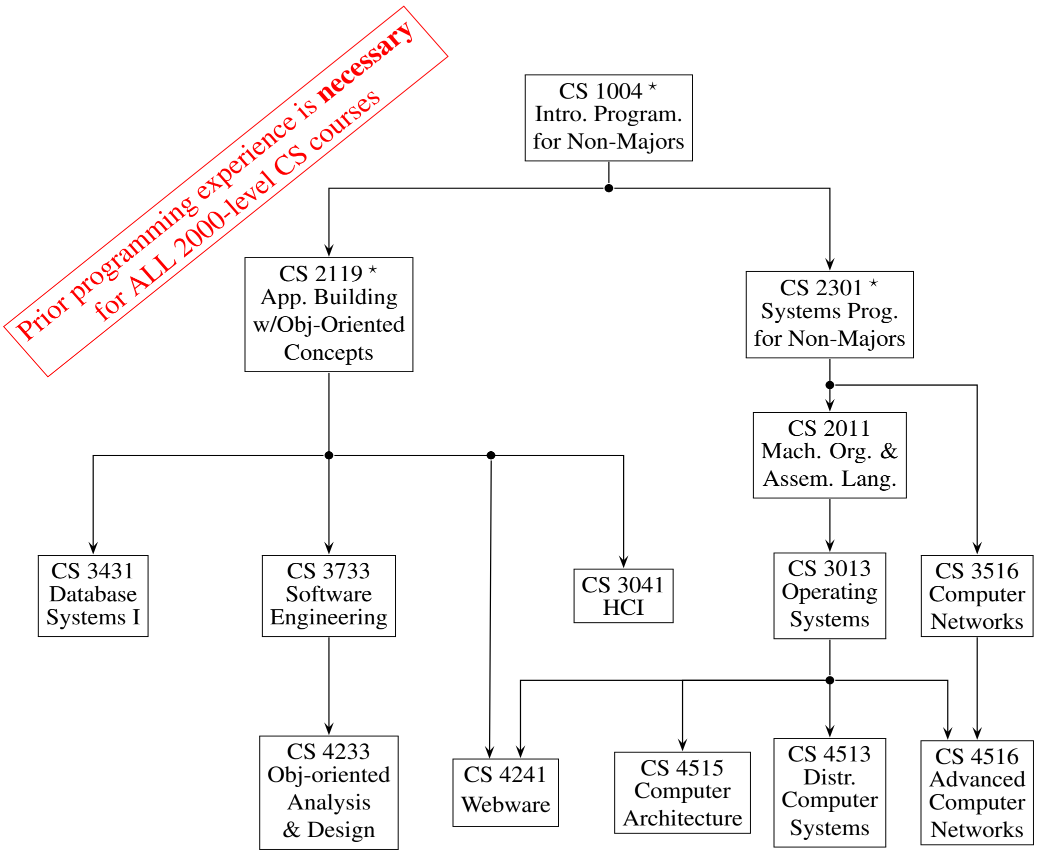
PROBABILITY—Minimum 1/3
MA 2621, MA 2631

2. Satisfy 1/3 units in courses discussing societal impacts of security from one of:
   a. Cyberlaw and Policy (GOV 2314)
   b. Social Implication of Information Processing (CS 3043)
   c. Other Cyber Security-related societal impacts courses subject to program approval
3. Satisfy 3/3 units in additional courses from:
   a. Operating Systems (CS 3013)
   b. Computer Networks (CS 3516)
   c. Advanced Computer Networks (CS 4516)
   d. Distributed Computing Systems (CS 4513)
   e. Mobile and Ubiquitous Computing (CS 4518)
   f. Any of the core Cyber Security courses listed above that are not used to meet the core requirement
   g. Other Cyber-Security-related courses subject to program approval
4. Complete a Cyber Security-related Major Qualifying Project, subject to program approval

Graduate courses may be counted towards the Cyber Security concentration at the discretion of the program.

COMPUTER SCIENCE COURSES FOR NON-MAJORS FLOW CHART

*Note: *The starred courses are designed for non-majors in need of computing preparation. They also provide needed background for specific CS-majors courses, as shown. The courses CS 2102 & CS 2303 can be substituted for CS 2119 & CS 2301, respectively.*



The Computer Science Courses for Non-Majors flowchart shows Computer Science courses that are particularly appropriate for students in need of computing preparation, but who are NOT majoring in Computer Science or one of its closely related fields. Consult the distribution requirements of each major to see the recommended CS courses for that major.

Please note: The three courses marked with an asterisk (i.e. CS 1004, CS 2119, and CS 2301) are less intense than the corresponding courses for Computer Science majors (CS 1101/1102, CS 2102/CS2103, and CS 2303, respectively). However, they do provide sufficient background for the CS courses shown on this chart.

This chart shows the most common sequence. However, non-majors are free to choose the courses for CS majors instead. That is, CS 1101 or CS 1102 can substitute for CS 1004; CS 2102, CS 210X, or CS 2103 can substitute for CS 2119; and CS 2303 can substitute for CS 2301.

DATA SCIENCE

E. A. RUNDENSTEINER, PROGRAM DIRECTOR
PROFESSORS: E. T. Loiacono, E. A. Rundensteiner, D. M. Strong, S.A. Zekavat
ASSOCIATE PROFESSORS: M. Y. Eltabakh, R. Paffenroth, C.Ruiz, A. Trapp, J. Zou
ASSISTANT PROFESSORS: L. T. Harrison, X. Kong, N.Kordzadeh, K. Lee, Y. Li, O. Mangoubi
ASSOCIATE TEACHING PROFESSOR: F. Emdad
ASSISTANT TEACHING PROFESSOR: C.K. Ngan

MISSION STATEMENT

Data Science prepares WPI undergraduates with the skills to understand, apply and develop models, algorithms and statistical techniques to gather huge amounts of data, draw new insights from it, and formulate appropriate action plans. Through courses and hands-on project work, students in the Data Science program will master foundational and advanced topics, including state-of-the-art data analytic technologies like machine/deep learning, artificial intelligence, and big data. This prepares the student to tackle the most critical data challenges in interdisciplinary teams with diverse perspectives in this increasingly digital world from climate change, self-driving cars, digital healthcare, to social justice. In addition to being a discipline in and of itself, Data Science complements many of the existing undergraduate majors at WPI. Disciplines from the sciences to engineering increasingly grapple with large data sets using computational and statistical techniques and tools.

Students interested in Data Science, both majors and minors, should check with the Data Science program as early as possible in their academic career to develop a plan of study. Students will be assigned a Data Science advisor after completing a major/minor declaration form.

PROGRAM EDUCATIONAL OBJECTIVES

In support of its goals and mission, the WPI Data Science undergraduate program's educational objectives are to graduate students who will:

- Bring together a community of diverse disciplinary backgrounds and experiential perspectives to promote creative solutions to critical real-world problems and advance knowledge at the cutting edge
- Achieve professional success due to their mastery of Data Science theory and practice
- Conduct impactful research and project work in data sciences tacking the world's most challenging problems
- Engage in discovery through purpose-driven project-based learning
- Collaborate with partners both internally and externally in interdisciplinary projects
- Become leaders in business, academia, and society due to a broad preparation in data science, computational thinking, mathematics, science & engineering, communication, and social issues
- Pursue lifelong learning and continuing professional development
- Use their understanding of the impact of data science on society for the benefit of humankind

Theme:
"Gather Information, Form Insights, Impact the World"!

PROGRAM OUTCOMES

Students graduating with a Bachelor of Science degree in Data Science:

- Have mastered foundational studies in business, computer science, and mathematical sciences
- Have mastered advanced principles and techniques in at least one of the three disciplines
- Can apply computational and mathematical knowledge to the solution of big data problems
- Can communicate effectively across disciplines both verbally and in writing
- Can locate, read, and interpret primary literature in data science
- Can function effectively as members of an interdisciplinary team
- Have an understanding of accepted standards of ethical and professional behavior
- Have the ability to be a life-long independent learner

Program Distribution Requirements for the Data Science Major

The distribution requirements for the BS degree in Data Science consists a series of interdisciplinary courses in Data Science, fundamental courses in Computer Science, Mathematical Sciences, and Business, and a set of more advanced courses selected primarily from the three supporting disciplines: Computer Science, Mathematical Sciences, and/or Business.

REQUIREMENTS	MINIMUM UNITS
1. Data Science Core Courses (Note 1)	3/3
2. Business (Note 2)	2/3
3. Computer Science (Note 3)	3/3
4. Mathematical Sciences (Note 4)	5/3
5. Data Privacy and Ethics (Note 5)	1/3
6. Natural or Engineering Sciences (Note 6)	2/3
7. Disciplinary Elective Courses (Note 7)	11/3
8. MQP (Note 8)	3/3

NOTES:

1. Students must complete the series of three DS core courses (DS 1010, DS 2010, and DS 3010)
2. Business foundation courses must include 1/3 unit in entrepreneurship and innovation, and 1/3 unit in business analysis:

   One of BUS 1010, ETR 1100, BUS 3010, ETR 3633

   One of BUS 2080 or OIE 2081
3. Computer science foundation courses must include 2/3 units of introductory computer science (with no more than 1/3 unit at the 1000 level) and 1/3 unit of algorithms. CS elective courses at level of 3000 and above as defined in Note 7 may substitute for introductory computer science credits.

   Two of CS 1004, 1101, 1102, CS 2102, CS 2103, CS 2119, or CS elective courses below.

   One of CS 2223
4. Mathematics foundation courses must include 2/3 units calculus, 2/3 units applied statistics, and 1/3 unit linear algebra. Mathematics disciplinary elective courses as defined in Note 7 may substitute for introductory calculus credits.

   Two of MA 1020, MA 1021, MA 1022, MA 1120, or disciplinary elective courses in MA as per Note 7. (Students cannot take both MA 1020 and

MA 1021 for credits. Students cannot take both MA 1022 and MA 1120 for credits.)

Both MA 2611, MA 2612

One of MA 2071, MA 2072

5. Data Privacy and Ethics. Choose 1/3 unit from among the following:

CS 3043

GOV 2313, GOV 2314, GOV 2315, GOV 2320

PY 2713, PY/RE 2731

RBE 3100

6. 2/3 units of work chosen in Natural or Engineering Science (courses with prefixes AE, AREN, BB, BME, CHE, CE, CH, ECE, ES, GE, ME, PH or RBE count).

7. Chosen from disciplinary elective courses in CS, MA, or BUS listed below.

At least one course must be selected from each of the following categories:

- Data access and management (CS 3431, MIS 3720, CS 4432, CS4433/DS4433)
- Data mining/machine learning (CS 4445, CS 4342)
- Business modeling and prediction (MIS 4084, OIE 4420)
- Disciplinary electives must include at least 4/3 units at the 4000 level or above.

8. Data Science MQP projects must have a MQP faculty advisor that has a formal collaborative appointment in the Data Science program.

Disciplinary Elective Courses in CS:

CS 2022 Discrete Mathematics
CS 2301 Systems Programming For Non-Majors
CS 2303 Systems Programming Concepts
CS 3133 Foundations of Computer Science
CS 3733 Software Engineering
+CS 3431 Database Systems I
CS 3041 Human-Computer Interaction
CS 4120 Analysis of Algorithms
+CS 4341 Introduction to Artificial Intelligence
+CS 4432 Database Systems II
+CS 4445 Data Mining and Knowledge Discovery in Databases
CS 4803/BCB 4003 Biological and Biomedical Database Mining
+CS 4342/DS 4342 Machine Learning
+CS 4804 Data Visualization
CS 4802/BCB 4002 Bio Visualization
+CS 4433/DS 4433 Big Data Management & Analytics
CS 4233 Object-Oriented Analysis and Design
CS 4241 Webware: Computational Technology for Network Information Systems

Students are encouraged to take elective courses with a (+) prefix.

Disciplinary Elective Courses in MA:

MA 1023 Calculus III
MA 1024 Calculus IV
MA 1033 Theoretical Calculus III
MA 1034 Theoretical Calculus IV
MA 2201 Discrete Mathematics
MA 2051 Ordinary Differential Equations
MA 2073 Matrices and Linear Algebra II
MA 2210 Mathematical Methods in Decision Making
MA 2431 Mathematical Modeling with Ordinary Differential Equations
+MA 2621 Probability for Applications
+MA 2631 Probability (Students cannot take both MA 2621 and MA 2631 for credits)
MA 3231 Linear Programming
MA 3233 Discrete Optimization
MA 3257 Numerical Methods for Linear and Nonlinear Systems
+MA 3627 Introduction to the Design and Analysis of Experiments
+MA 3631 Mathematical Statistics
MA 4213 Loss Models I - Risk Theory
MA 4214 Loss Models II - Survival Models
MA 4235 Mathematical Optimization
MA 4237 Probabilistic Methods of Operations Research
+MA 4603 Statistical Methods in Genetics and Bioinformatics
MA 4631 Probability and Mathematical Statistics I
MA 4632 Probability and Mathematical Statistics II
+MA 4635/DS4635 Data Analytics and Statistical Learning

Students are encouraged to take elective courses with a (+) prefix.

Disciplinary Elective Courses in BUS:

+MIS 3720 Business Data Management
MKT 3650 Consumer Behavior
OIE 3460 Simulation Modeling and Analysis
+MIS 4084 Business Intelligence
MIS 4720 Systems Analysis and Design
MIS 4741 User Experience and Design
+OIE 4420 Practical Optimization: Methods and Applications

Students are encouraged to take elective courses with a (+) prefix.

MINOR IN DATA SCIENCE

MISSION STATEMENT

The Minor in Data Science prepares WPI undergraduates in any major with the skills essential to understand and work with data by applying models, algorithms and statistical techniques to extract, model, analyze and predict data.The minor complements many of the existing undergraduate majors at WPI from sciences to engineering that increasingly must work with large digital data sets using computational and statistical techniques and tools by providing these students with the core competencies of Data Science.

Students interested in the minor should meet with the Data Science minor advisor as early as possible in their academic career to develop a plan of study.They will be assigned a Data Science minor advisor after completing a minor declaration form.

DATA SCIENCE MAJOR PROGRAM CHART

UNIVERSITY REQUIREMENTS	
Minimum Academic Credit	15 Units
Residency	8 Units
Humanities and Arts	6/3 Units
Interactive Qualifying Project	3/3 Unit
Social Science	2/3 Unit
Physical Education	1/3 Unit
Free Electives	3/3 Unit

MAJOR-SPECIFIC REQUIREMENTS (10 UNITS)	
DS Core Courses*	3/3 Unit
Disciplinary Foundation Courses	10/3 Units
Disciplinary Electives	11/3 Units
DS MQP	3/3 Unit
Data Privacy and Ethics	1/3 Unit
Sciences	2/3 Unit

(*) DS core courses include DS 1010, DS 2010, DS 3010.

DISCIPLINARY FOUNDATION COURSES (10/3 UNITS)

COMPUTER SCIENCE COURSES (3/3 Unit Required)	MATHEMATICS COURSES (5/3 Unit Required)	BUSINESS COURSES (2/3 Unit Required)
Two of CS 1004, CS 1101, CS 1102, CS 2102, CS 2103, CS 2119, or from CS electives below (**) **AND** One of CS 2223	Two of MA 1020, MA 1021, MA 1022, MA 1120, or from MA electives below **AND** Both MA 2611 and MA 2612 **AND** One of MA 2071 or MA 2072	One of BUS 1010, ETR1100, BUS 3010, ETR 3633 **AND** One of BUS 2080 or OIE 2081

(**) At most 1/3 CS unit at the 1000 level.

DISCIPLINARY ELECTIVE COURSES (11/3 UNITS)

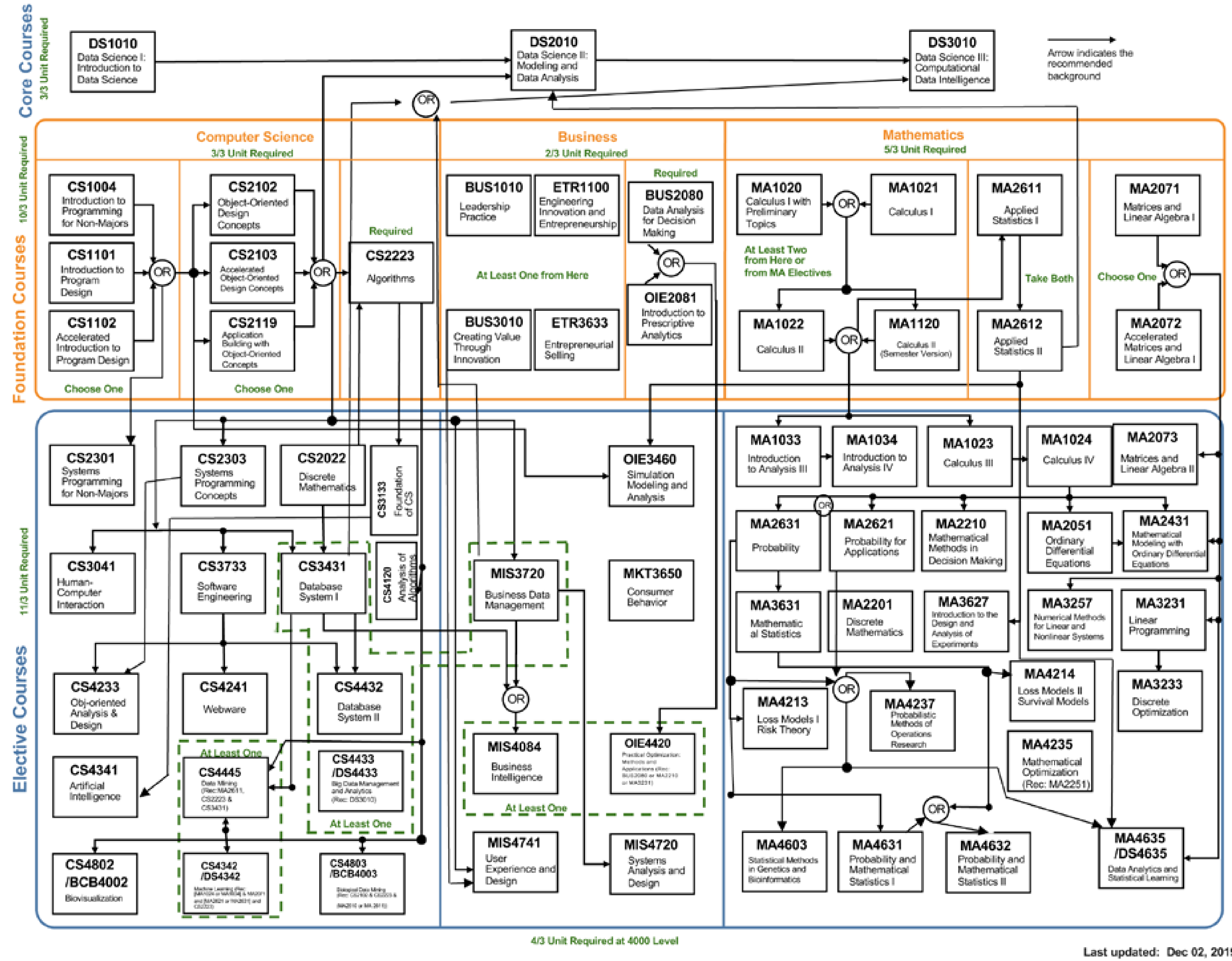
COMPUTER SCIENCE COURSES		MATHEMATICS COURSES		BUSINESS COURSES
CS 2022	+CS 4341	MA 1023	MA 3257	+MIS 3720
CS 2301	CS 4120	MA 1024	+MA 3627	MKT 3650
CS 2303	+CS 4432	MA 1033	+MA 3631	OIE 3460
CS 3733	+CS 4445	MA 1034	MA 4213	+MIS 4084
CS 3041	+CS 4342/DS4342	MA 2051	MA 4214	MIS 4720
CS 3133	+CS 4804	MA 2073	MA 4235	MIS 4741
+CS 3431	+CS 4433/DS4433	MA 2201	MA 4237	+OIE 4420
CS 4233	CS 4802/BCB4002	MA 2210	+MA 4603	
CS 4241	CS 4803/BCB4003	MA 2431	MA 4631	
		+MA 2621	MA 4632	
		+MA 2631	+MA4635/DS4635	
		MA 3231	MA 3233	

Electives must include at least one course in each of the categories below:

- Databases (CS 3431, CS 4432, MIS 3720, CS 4433/DS 4433)
- Data mining/machine learning (CS 4445, CS 4342/DS4342)
- Business modeling and prediction (MIS 4084, OIE 4420)

Electives must include at least 4/3 at the 4000 level or above.
Students are encouraged to take electives marked with a "+".

DATA SCIENCE COURSES FOR MAJORS FLOW CHART



Last updated: Dec 02, 2019

The **Minor in Data Science** will consist of 2 units, all of which must be selected from the list of approved Data Science major courses. These 2 units must be selected to include the following:

- Three courses, one from each of the three areas (Business, Computer Science, Mathematical Sciences) at the 2000 level or above from the list of disciplinary courses approved for the Data Science major
- At least two courses out of the DS series DS 1010, DS 2010, and DS 3010.
- At least one course at the 3000 level or above selected from the list of disciplinary courses approved for the Data Science major.

The Minor in Data Science is open to all undergraduate majors at WPI. Students majoring in Business, Computer Science, or Mathematical Sciences should consult WPI rules on minors for double-counting courses.

LIST OF APPROVED COURSES FOR THE DATA SCIENCE MINOR

Any graduate course approved for the Data Science graduate program can also be counted towards the Data Science minor. These courses are not repeated here.

Data Science Core Courses:

- DS 1010 Data Science I: Introduction to Data Science
- DS 2010 Data Science II: Modeling and Data Analysis
- DS 3010 Data Science III: Computational Data Intelligence

Business Courses:

- BUS 2080 Data Analysis for Decision Making**
- BUS 3010 Creating Value Through Innovation
- ETR 3633 Entrepreneurial Selling
- MIS 3720 Business Data Management
- MIS 4084 Business Intelligence
- MIS 4720 Systems Analysis and Design
- MIS 4741 User Experience and Design
- MKT 3650 Consumer Behavior
- OIE 2081 Introduction to Prescriptive Analytics**
- OIE 3460 Simulation Modeling and Analysis
- OIE 4420 Practical Optimization: Methods and Applications

Computer Science Courses:

- CS 1004 Introduction to Programming for Non-Majors
- CS 1101 Introduction to Program Design *
- CS 1102 Accelerated Introduction to Program Design *
- CS 2102 Object-Oriented Design Concepts‡
- CS 2103 Accelerated Object-Oriented Design Concepts‡
- CS 2022 Discrete Mathematics
- CS 2119 Application Building with Object-Oriented Concepts
- CS 2223 Algorithms
- CS 2301 Systems Programming for Non-majors
- CS 2303 Systems Programming Concepts
- CS 3041 Human-Computer Interaction
- CS 3133 Foundation of Computer Science
- CS 3431 Database Systems I
- CS 3733 Software Engineering
- CS 4120 Analysis of Algorithms
- CS 4233 Object-Oriented Analysis and Design
- CS 4241 Webware
- CS 4341 Introduction to Artificial Intelligence
- DS/CS 4342 Machine Learning
- CS 4432 Database Systems II
- DS/CS 4433 Big Data Management and Analytics
- CS 4445 Data Mining and Knowledge Discovery in Databases
- CS 4802 Biovisualization
- CS 4803 Biological and Biomedical Database Mining
- CS 4804 Data Visualization

Mathematical Sciences Courses:

- MA 2051 Ordinary Differential Equations
- MA 2071 Linear Algebra
- MA 2072 Accelerated Matrices and Linear Algebra I
- MA 2073 Matrices and Linear Algebra II
- MA 2201 Discrete Mathematics
- MA 2210 Mathematical Methods in Decision Making
- MA 2431 Mathematical Modeling with Ordinary Differential Equations
- MA 2611 Applied Statistics I
- MA 2612 Applied Statistics II
- MA 2621 Probability for Applications†
- MA 2631 Probability Theory†
- MA 3231 Linear Programming
- MA 3233 Discrete Optimization
- MA 3257 Numerical Methods for Linear and Nonlinear Systems
- MA 3627 Introduction to the Design and Analysis of Experiments
- MA 3631 Mathematical Statistics
- MA 4213 Loss Models – Risk Theory
- MA 4214 Loss Models – Survival Models
- MA 4235 Mathematical Optimization
- MA 4237 Probabilistic Methods in Operations Research
- MA 4603 Statistical Methods in Genetics and Bioinformatics
- MA 4631 Probability and Mathematical Statistics I
- MA 4632 Probability and Mathematical Statistics II
- DS/MA 4635 Data Analytics and Statistical Learning

* Credit may not be earned for both CS 1101 and CS 1102
† Credit may not be earned for both MA 2621 and MA 2631
‡ Credit may not be earned for both CS 2102 and CS 2103
** Credit may be earned for both BUS 2080 and OIE 2081

ELECTRICAL AND COMPUTER ENGINEERING

D. R. BROWN, HEAD; R. LUDWIG, ASSOCIATE HEAD

PROFESSORS: D. R. Brown, E. A. Clancy, X. Huang, R. Ludwig, S. Makarov, J. A. McNeil, W.R. Michalson, K. Pahlavan, P. Schaumont, B. Sunar, R.F. Vaz, A. Wyglinski

ASSISTANT PROFESSORS: S. Bhada, A. Clark, J. Fu, U. Guler, Z. Zhang

ASSISTANT TEACHING PROFESSORS: G. Bogdanov, Y. Doroz, M. Mughal, K. Mus, S. Ramabhotla

ADJUNCT PROFESSORS: G. Prince, G. Noetscher, J. Stander

INSTRUCTOR: S. J. Bitar

EMERITUS PROFESSORS: K. A. Clements, D. Cyganski, J. S. Demetry, A.E. Emanuel, F. J. Looft, J. A. Orr, P. C. Pedersen

ASSOCIATED FACULTY : E. Agu (CS), G. Fischer (ME), C Furlong (ME), M. Gennert (CS), Y. Mendelson (BME), L. Ramdas Ram-Mohan (PH), J. Sullivan (ME), K. Venkatasubramianian (CS)

MISSION STATEMENT

To be prepared for employment as a contributing engineer and/or for graduate-level education, students within the ECE Department receive instruction that is balanced between theory and practice. In fact, much of our curriculum integrates theory and practice within each course. It is common to study new devices and techniques, and then immediately work with these devices/techniques in a laboratory setting. In response to the breadth of ECE, all students work with their academic advisor to develop a broad-based program of study. As with most engineering curricula, ECE study includes a solid foundation of mathematics and science. Discipline-specific study in ECE usually begins early in a student's career — during the second half of the freshman year — with courses providing a broad overview of the entire field. During the sophomore and junior years, students learn the core analysis, design and laboratory skills necessary to a broad range of ECE sub-disciplines. When desired, specialization within ECE occurs during the junior and senior years. In addition, all students complete a major qualifying project (MQP). This project, typically completed in teams during the senior year, is an individualized design or research project that draws from much of the prior instruction. Utilizing the benefit of individualized instruction from one or more faculty members, students develop, implement and document the solution to a real engineering problem. Many of these projects are sponsored by industry, or are associated with ongoing faculty research. These projects form a unique bridge to the engineering profession.

PROGRAM EDUCATIONAL OBJECTIVES

The Electrical and Computer Engineering Department offers a balanced, integrated curriculum strong in both fundamentals and state-of-the-art knowledge. The curriculum embraces WPI's philosophy of education, with a program characterized by curricular flexibility, student project work such as the Interactive Qualifying Project, and active involvement of students in their learning.

The Electrical and Computer Engineering Program seeks to have alumni who:

- are successful professionals who demonstrate in their work a breadth of knowledge in the field of electrical and computer engineering,
- are engaged in graduate study or other forms of lifelong learning;
- are effective contributors in business and society, demonstrating the ability to communicate, work in teams, and understand the broad implications of their work;
- are engaged broadly in both their professional and personal lives, exhibiting effective leadership and informed citizenship.

STUDENT OUTCOMES

Based on the department's educational objectives, students will achieve the following specific educational outcomes within a challenging and supportive environment:

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. an ability to communicate effectively with a range of audiences.
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Program Distribution Requirements for the Electrical and Computer Engineering Major

The normal period of residency at WPI is 16 terms. In addition to WPI requirements applicable to all students, students wishing to receive the ma jor designated "Electrical and Computer Engineering" must satisfy certain distribution requirements. These requirements apply to 10 units of study in the areas of mathematics, basic science, and engineering science and design as follows:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Basic Science (Notes 1a-1d)	4
2. Engineering Science and Design (ES/D) (including the MQP) (Notes 2a-2g)	6

NOTES:

1. Mathematics and Basic Science:
   a. Must include at least 7/3 units of math (prefix MA). Mathematics must include differential and integral calculus, differential equations, and probability.
   b. Must include at least 2/3 units of physics (prefix PH).
   c. Must include at least 1/3 units of chemistry (prefix CH) or 1/3 units biology (prefix BB).
   d. Must include an additional 2/3 units of math or basic science (prefixes MA, PH, CH, BB, or GE).
2. Engineering Science and Design (including the MQP):
   a. Must include at least 5 units at the 2000-level or higher within the Electrical and Computer Engineering area (including the MQP). All courses with prefix ECE at the 2000-level or higher and ES 3011 are applicable to these 5 units.
   b. The 5 units within the Electrical and Computer Engineering area must include at least 1 unit of courses from these approved Electrical Engineering courses: ECE 2112, ECE 2201, ECE 2305, ECE 2312, ECE 3012 (or ES 3011), ECE 3113, ECE 3204, ECE 3308, ECE 3311, ECE 3500, ECE 501, ECE 3503, ECE 4011, ECE4023, ECE 4305, ECE 4703, ECE 4902, and ECE 4904.
   c. The 5 units within the Electrical and Computer Engineering area must include at least 2/3 unit of courses from these approved Computer Engineering courses: ECE 2029, ECE 2049, ECE 3829, ECE 3849 and ECE 4801.
   d. The 5 units within the Electrical and Computer Engineering area must include 1/3 unit of Capstone Design Experience. (This requirement is typically fulfilled by the MQP.)
   e. Must include at least 1/3 unit of computer science (prefix CS), at the 2000-level or above (other than CS 2011, CS 2022, CS 3043 which cannot be applied to this requirement).
   f. Must include an additional 2/3 unit of engineering science and design at the 2000-level or above, selected from courses having the prefix AE, AREN, BME, CE, CHE, CS (other than CS 2011, CS 2022, CS 3043), ECE, ES, FP, ME, or RBE.

SUBDISCIPLINES WITHIN ECE

Given a solid foundation, the MQP will allow you to demonstrate an in-depth understanding of one or more of the subdisciplines that compose the field of electrical and computer engineering. As a guide to the areas of study that can be investigated in an MQP, the ECE Course Flowchart identifies seven subdisciplines as possible areas for in-depth study leading to an MQP. Note that students should not feel constrained by these area designations — this is only one of many possible ways to organize the diverse field of electrical and computer engineering. Many if not most MQPs will incorporate subject matter from several different subdisciplines. The purpose of this list is to guide students interested in a particular area to coursework within a subdiscipline (Area Courses), relevant courses to choose from outside the subdiscipline (Related Courses), and faculty whose research and MQP advising interests fall within the subdiscipline (Area Consultants).

Robotics

Area Consultants: Fu, Michalson, Wyglinski

Area Courses

ECE 2029 Introduction to Digital Circuit Design
ECE 2049 Embedded Computing in Engineering Design
ECE 3849 Real-time Embedded Systems
ES 3011 Control Engineering I

Related Courses

CS 4341 Artificial Intelligence
ECE 2201 Microelectronics I
ECE 3503 Power Electronics
RBE 1001 Introduction to Robotics
RBE 2001 Unified Robotics I: Actuation
RBE 2002 Unified Robotics II: Sensing
RBE 3001 Unified Robotics III: Manipulation
RBE 3002 Unified Robotics IV: Navigation

Power Systems Engineering

Area Consultants: Mughal, Ramabhotla

Area Courses

ECE 3500 Introduction to Contemporary Electric Power Systems
ECE 3501 Electrical Energy Conversion
ECE 3503 Power Electronics

Related Courses

ES 3001 Introduction to Thermodynamics
ES 3011 Control Engineering I
ME 1800 Manufacturing Science Prototyping and Computer-Controlled Machining
OIE 2850 Engineering Economics

RF Circuits and Microwaves

Area Consultants: Ludwig, Makarov

Area Courses

ECE 2112 Electromagnetic Fields
ECE 3113 RF Circuit Design

Related Courses

MA 4451 Boundary Value Problems
PH 3301 Electromagnetic Theory
PH 3401 Quantum Mechanics I
PH 3504 Optics

Communications and Signal Analysis

Area Consultants: Brown, Clancy, Makarov, Pahlavan, Wyglinski

Area Courses

ECE 2305 Introduction to Communications and Networks
ECE 2312 Discrete-Time Signal and System Analysis
ECE 3308 Introduction to Wireless Networks
ECE 3311 Principles of Communication Systems
ECE 4305 Software-Defined Radio Systems and Analysis
ECE 4703 Real-Time Digital Signal Processing

Related Courses

ES 3011 Control Engineering I
MA 2071 Matrices and Linear Algebra I
MA 2621 Probability for Applications
MA 4291 Applicable Complex Variables

Biomedical Engineering

Area Consultants: Clancy

Area Courses

ECE/BME 4011 Biomedical Signal Analysis
ECE/BME 4023 Biomedical Instrumentation Design

Related Courses

BME 4201 Biomedical Imaging
ECE 2201 Microelectronic Circuits I
ECE 2312 Discrete-Time Signal and System Analysis
ECE 3204 Microelectronic Circuits II

Analog Microelectronics

Area Consultants: Bitar, Guler, Ludwig, McNeill

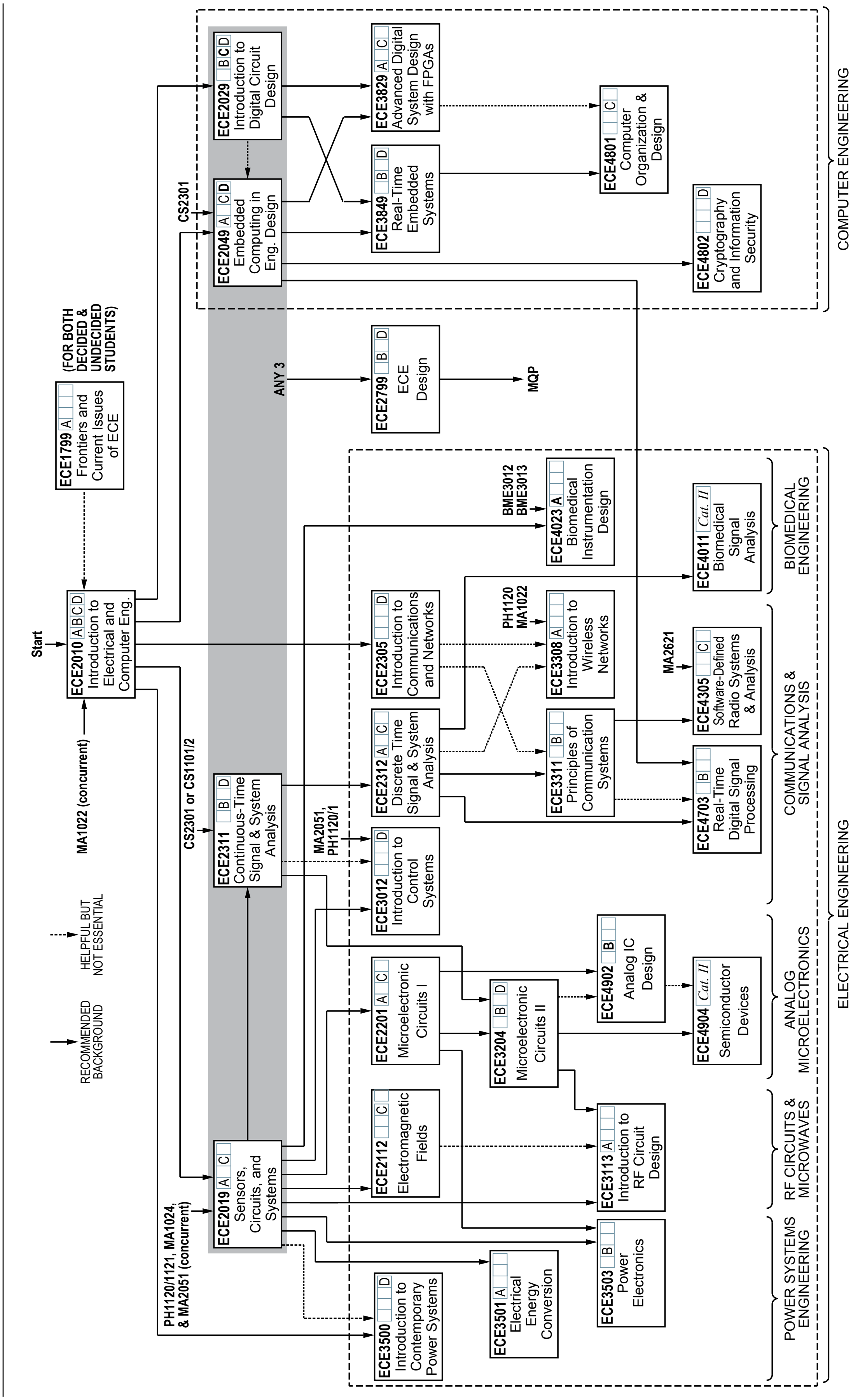
Area Courses

ECE 2201 Microelectronics I
ECE 3204 Microelectronics II
ECE 4902 Analog Integrated Circuit Design
ECE 4904 Semiconductor Devices

Related Course

ES 3011 Control Engineering I

ELECTRICAL AND COMPUTER ENGINEERING COURSE FLOW CHART



Computer Engineering
Area Consultants: Bogdanov, Clancy, Huang, Looft, Michalson, Sunar

Area Courses

ECE 2029	Introduction to Digital Circuit Design
ECE 2049	Embedded Computing in Engineering Design
ECE 3829	Advanced Digital System Design with FPGAs
ECE 3849	Real-time Embedded Systems
ECE 4801	Computer Organization and Design

Related Courses

ECE 2201	Microelectronics I
CS 2223	Algorithms
CS 3013	Operating Systems
CS 3733	Software Engineering
CS 4515	Computer Architecture
CS 4536	Programming Languages

OVERVIEW OF OTHER PROGRAM COMPONENTS

ENGINEERING SCIENCE AND DESIGN

Because modern engineering practice is increasingly interdisciplinary, all students achieve some breadth of study outside of the ECE department by taking a minimum of one Computer Science and two Engineering Science and Design courses. These courses must be at the 2000-level or higher, and certain courses with limited technical content are not credited towards this requirement. (See the formal requirements listed previously in the distribution requirements.) Many students find it advantageous to take more than the minimum CS course requirement. CS 2301 is highly recommended for ECE students.

MATHEMATICS AND SCIENCE

To succeed in the study of electrical and computer engineering, the necessary foundation far exceeds what can be taught in a few introductory courses. In fact, if you even want to begin to understand what your ECE professors are talking about in lecture, you must begin with a firm basis in mathematics and the natural sciences. Moreover, whether applied to ECE or not, proficiency in mathematics and the sciences is a necessary quality for any educated engineer. Consequently, the ECE major requires a total of 4 units (12 courses) as the "Mathematics and Basic Science" distribution requirement.

The first part of this requirement is sufficient education in mathematics. At least 7 of the 12 required courses must be in this area, including coursework in differential calculus, integral calculus, differential equations, and probability. To see which specific courses fulfill these math requirements, please consult the mathematics course descriptions, and your academic advisor.

The other part of the requirement is coursework in the sciences. A solid understanding of physics is essential to any ECE student, being ultimately necessary for describing the behavior of electricity and magnetism as well as other physical phenomena. Knowledge of chemistry is useful as well, encompassing such topics as atomic and molecular behavior and the chemical properties of materials (such as silicon, which is quite useful in ECE). In recent years, knowledge of biology has also become important to electrical and computer engineers, particularly as biomedical-electrical technologies such as medical imaging continue to advance.

The ECE major requires at least 3 courses in the sciences, 2 of these courses must be in physics, and the remaining course may be in chemistry or biology depending on preference.

Finally, note that the total prescribed mathematics and science courses add up to 3 1/3 units (10 courses). To meet the distribution requirement, you then must take at least 2 more courses in any area of mathematics or science (that is, any other course with the prefix "MA", "PH", "CH", "BB", or "GE").

MINOR IN ELECTRICAL AND COMPUTER ENGINEERING

For students who are not ECE majors and are interested in broadening their exposure to and understanding of electrical and computer engineering, the ECE department offers a Minor. This Minor provides an exciting opportunity to acquire a solid knowledge of electrical and computer engineering as needed in today's diverse and technology driven society.

Successful candidates for the ECE Minor must meet the following requirements:

1. Complete two units of work from courses with the prefix "ECE" at the 2000-level or above.
2. Of the work in (1), at least 2/3 unit must be from ECE courses at the 3000-level or above which are thematically related.

The ECE minor form, available in the ECE office, lists examples of thematically related courses in different areas of concentration. Students seeking an ECE Minor should complete the ECE Minor form and submit it to the ECE office as early in the program of study as possible. The chair of the ECE curriculum committee will be responsible for review and approval of all ECE Minor requests.

WPI policy requires that no more than one unit of course work can be double counted toward other degree requirements.

ENGINEERING SCIENCE COURSES

In the formation of a program of study for any engineering or science student, it is important to emphasize a significant number of interdisciplinary courses which form the fundamental building blocks of so many scientific and engineering activities.

In addition to those courses in science and mathematics which are an important part of every engineer's background at WPI, there are a number of courses containing subject matter common to a variety of disciplinary interests. These courses are known as the "engineering science group" and are often taught jointly by members of more than one department.

Every engineer, for example, needs to have some knowledge of graphics, the communications tool of engineering; of thermodynamics, the consideration of an important aspect of energy and its laws; of mechanics, solid and fluid, static and dynamic, the treatment of forces and their effects on producing motion. These and certain other courses of either basic knowledge or broad application are grouped in the engineering science series to provide special focus on them for all students interested in applied science or engineering. In developing programs to meet engineering science distribution requirements, students and advisors should give careful attention to these engineering science courses.

ENVIRONMENTAL ENGINEERING

DIRECTOR: J. BERGENDAHL (CEE)

ASSOCIATED FACULTY: J. Bergendahl (CEE), T. Camesano (CHE), D. DiBiasio (CHE), J. Dudle (CEE), C. M. Eggleston (CEE), S. Kmiotek (CHE), S. LePage (CEE), P. Mathisen (CEE), M. Tao (CEE), H. Walker (CEE)

MISSION STATEMENT

Environmental engineers are challenged not only with mastering technical and scientific principles, but also understanding the broader context within which environmental solutions are implemented. The environmental engineering program encourages coursework in the humanistic and social aspects of engineering decisions, public health management, and environmental preservation. The projects program at WPI offers environmental engineering students a unique opportunity to explore the complex humanistic, economic, legal, and political issues surrounding environmental engineering problems.

The Environmental Engineering degree program prepares students for careers in both the private and public sectors, consulting, industry, and advanced graduate study.

PROGRAM EDUCATIONAL OBJECTIVES

The Program Educational Objectives for the Bachelor degree in Environmental Engineering are that our alumni will:

1. Have successful careers in environmental engineering and related professions, where sound science and engineering principles are applied to solve environmental problems in a socially and ethically responsible manner.
2. Be leaders who are at the forefront of environmental change for the betterment of ecosystems and quality of life.
3. Meet the changing needs of the profession through lifelong learning, such as graduate eduction, engagement in the profession and organizations, and attainment of professional licensure.

STUDENT OUTCOMES

The Student Outcomes for the Bachelor degree in Environmental Engineering are that all graduates will attain:

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Program Distribution Requirements for the Environmental Engineering Major

The normal period of residency at WPI is 16 terms. In addition to WPI requirements applicable to all students, students wishing to receive the ABET accredited degree designated “Environmental Engineering” must satisfy certain distribution requirements as follows:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Basic Science (Note 1)	4
2. Advanced Science (Note 2)	1
3. Engineering Science and Design (Includes MQP) (Note 3)	6

NOTES:

1. Mathematics and Basic Science
   a. Must include 6/3 units of mathematics, including differential and integral calculus, differential equations, and statistics.
   b. Must include 6/3 units of basic science, including 1/3 unit of biology (BB), 3/3 units of chemistry (CH), 1/3 unit of earth science (GE 2341 recommended) and 1/3 unit of PH (calculus based).
2. Advanced Science: Must include 3/3 units of science in biology (BB) and chemistry (CH) with a minimum of 1/3 unit in BB and 1/3 unit in CH. Advanced BB courses must be at the 2000-level or higher. Advanced CH courses include CH 1040 and CH courses at the 2000-level or higher. Courses may not be double-counted toward the basic science requirement.
3. Engineering Science and Design
   a. Must include 2/3 units in thermofluids, including 1/3 unit in fluid mechanics (ES 3004 recommended) and 1/3 unit in thermodynamics (ES 3001, CHE 2013, or CH 3510).
   b. Must include 2/3 units in mechanics and materials (CE 2000 or ES 2501, CE 2001 or ES 2502, ES 2001, ES 2503).
   c. Must include 3/3 units of Core Environmental Engineering (CHE 2011, CE 3059, CE 3062, CHE 3201).
   d. Must include 6/3 units in Environmental Engineering Electives, arranged as follows: 3/3 units in water quality and resources, 2/3 units in air and land environmental systems, and 1/3 unit in environmental management.
   e. Must include 1/3 unit of environmental health issues (CE 3059, CE 3060, CE 3061, or appropriate experience through IQP, independent study, or appropriate consortium courses).
   f. Must include 2/3 units with laboratory experimentation. Must include either CE 4060 or CHE 4401. The remaining 1/3 unit may be CE 4060, CHE 4401, laboratory courses in CH (CH 2640 or CH 2650, which would satisfy Advanced Science course requirements), CE 3026, or CE 2020.
   g. Must include 1/3 unit major design experience through the MQP, or other approved design experience in a course such as CHE 4403 or ME 4429.

For more information, please consult the web site for this major at http://wpi.edu/academics/eve

ENVIRONMENTAL ENGINEERING PROGRAM CHART

STUDENTS EARNING AN ABET ACCREDITED BACHELOR DEGREE IN ENVIRONMENTAL ENGINEERING MUST COMPLETE A MINIMUM OF 15 UNITS OF STUDY, DISTRIBUTED AS FOLLOWS:

MATHEMATICS AND BASIC SCIENCE (4 Units Required)

Differential and integral calculus; differential equations	5/3 units
Statistics (MA 2611 recommended)	1/3 unit
Biology (BB)	1/3 unit
Chemistry (CH)	3/3 units
Earth science (GE 2341 recommended)	1/3 unit
Physics (PH)	1/3 unit

ADVANCED SCIENCE (1 Unit Required)

Must include 3/3 units of science in biology (BB) and chemistry (CH) with a minimum of 1/3 unit in BB and 1/3 unit in CH. Advanced BB courses must be at the 2000-level or higher. Advanced CH courses include CH 1040 and CH courses at the 2000-level or higher. Courses may not be double-counted toward the basic science requirement.

ENGINEERING SCIENCE AND DESIGN (6 Units Required; 5 1/3 units as arranged below plus 2/3 units free electives in ES&D at the 2000-level or above).

Please consult the program distribution requirements for detailed information on course requirements and selection. Project must include 2/3 units with laboratory experimentation.

Engineering Science

Thermofluids — **minimum 2/3 units**

- ES 3001 Introduction to Thermodynamics (or CHE 2013 or CH 3510)
- ES 3002 Mass Transfer
- ES 3004 Fluid Mechanics

Mechanics and Materials — **minimum 2/3 units**

- CE 2000 Analytical Mechanics I (or ES 2501)
- CE 2001 Analytical Mechanics II (or ES 2502)
- ES 2001 Introduction to Material Science
- ES 2503 Introduction to Dynamic Systems

Core Environmental Engineering — **minimum 3/3 units**

- CHE 2011 Chemical Engineering Fundamentals
- CE 3059 Environmental Engineering
- CE 3062 Hydraulics in Civil Engineering
- CHE 3201 Kinetics and Reactor Design

Environmental Engineering Electives

Water Quality and Resources — **minimum 3/3 units**

- CE 3060 Water Treatment
- CE 3061 Wastewater Treatment
- CE 4060 Environmental Engineering Laboratory
- CE 4061 Hydrology

Air and Land Environmental Systems — **minimum 2/3 units**

- CE 3041 Soil Mechanics
- CE 3074 Environmental Analysis
- CE 4600 Hazardous and Industrial Waste Management
- CE/CHE 4063 Transport and Transformations in the Environment
- CHE 4401 Unit Operations of Chemical Engineering I

Environmental Management — **minimum 1/3 unit**

- CE 3020 Project Management
- CE 3070 Urban and Environmental Planning
- CE 4071 Land Use Development and Controls

Major Qualifying Project — **3/3 units**

ADDITIONAL DEGREE REQUIREMENTS (4 units Required)

Humanities and Arts	6/3 units
Social Science‡	2/3 units
IQP	3/3 units
Physical Education	1/3 unit

‡ Many SS courses compliment topics in environmental engineering. Courses in policy, regulations, law and environmental problems are recommended.

FIRE PROTECTION ENGINEERING

A. SIMEONI, HEAD

PROFESSORS: N. A. Dembsey, A. Rangwala, A. Simeoni
ASSOCIATE PROFESSOR: K. A. Notarianni
ASSISTANT PROFESSOR: J. Urban
PROFESSOR OF PRACTICE: M. Puchovsky
ADJUNCT FPE FACULTY: W. Krein, J. Tubbs, C. Wood,
EMERITUS PROFESSORS: R. W. Fitzgerald, D. A. Lucht, R. E. Zalosh
ASSOCIATED FACULTY: L. Albano (CEE), J. Liang (ME)

MISSION STATEMENT

To deliver a high quality fire protection engineering education program for both full-time students and practicing professionals, supported by fire research in selected areas of strength.

PROGRAM EDUCATIONAL OBJECTIVES

- To deliver a comprehensive fire protection engineering degree/certificate program that is consistent with changes in technology and the environment.
- To maximize the use of educational technology to deliver for-credit courses to both part time and full time students, on and off campus worldwide.

COMBINED BS/MS DEGREE PROGRAM

A combined-degree program is available for those undergraduate students having a strong interest in fire protection. This program provides students with the opportunity to accelerate their graduate work by careful development of their undergraduate plan of study leading to a Bachelor degree in a field of engineering and a master's degree in fire protection engineering. The combined-degree approach saves time and money since up to 40 percent of course credits counted towards the Master's degree can also be counted toward the Bachelor degree. Holders of a Bachelor degree in traditional engineering or science disciplines and the Master's degree in fire protection engineering enjoy extremely good versatility in the job market.

FIRE PROTECTION ENGINEERING FIVE-YEAR PROGRAM

High school seniors can be admitted to the combined-degree program as freshmen, allowing them to complete both a bachelor's degree in a selected field of engineering followed by the master's degree in fire protection engineering, in a total of five years.

HUMANITIES AND ARTS

K. MONCRIEF, HEAD;
J. COCOLA, D. WEEKS, ASSOCIATE HEADS

PROFESSORS: F. Bianchi, K. Boudreau, J. J. Brattin, S. C. Bullock, J. deWinter, B. Faber, R. S. Gottlieb, J. P. Hanlan, P. H. Hansen, K. Moncrief, J. Rudolph, L. E. Schachterle
ASSOCIATE PROFESSORS: S. Barton, C. Clark, J. Cocola, B. Eddy, M. Ephraim, A. S. Madan, V. Manzo, J. McWeeny, A. A. Rivera, J. Rosenstock, M. D. Samson, J. Sanbonmatsu, D. Spanagel
ASSISTANT PROFESSORS: D. DiMassa, H. Droessler, E. Gutierrez, K. McIntyre, Y Telliel
PROFESSOR OF PRACTICE: K. Lewis
TEACHING PROFESSORS: L. Higgins, D. Weeks
ASSOCIATE TEACHING PROFESSORS: E. Boucher-Yip, U. Brisson, J. Cullon, J. Harmon, R. Madan, I. Matos-Nin, S. Nikitina
ASSISTANT TEACHING PROFESSORS: J. Aguilar, A. Danielski, L. Davis, W. Du, R. Falco, J. Galante, M. Halpine, M. Keller, S. Lessing, R. Moody, G. Pfeifer, J. Rohde, W. San Martín, H. Zheng
ADJUNCT TEACHING PROFESSORS: W. Addison, W. Baller
SENIOR INSTRUCTOR: R. Bigonah
INSTRUCTOR/LECTURERS: M. Brahimi, P. Crowe, M. El Hamzaoui, D. Giapoudzi, A. Gonzalez
ADJUNCT FACULTY: J. Blumhofer, P. Buono, S. Burton, J. Duquette, P. Everett, M. Hatch Moysey, D. Ibbett, P. Kirby, D. Manzo, S. Minichiello, C. Nakajima, D. Olsen, T. O'Malley, M. Pietrucha, J. Policelli, J. Reinhardt, S. Runstrom, P. Russell, G. Scott, M. Sethi, A. Shafer, A. Vaudreuil, M. Warren, B. Wetters, F. Yu
PROFESSORS EMERITUS: W. A. B. Addison, Jr., D. B. Dollenmayer, L. Fontanella, E. Hayes, C. Heventhal, K. P. Ljungquist, J. Manfra, L. Menides, W. T. Mott, E. M. Parkinson, T. Shannon, R. L. Smith, M. Sokal, S. Vick, J. Zeugner

MISSION STATEMENT

We are committed to helping students develop both a knowledge of, and an ability to think critically about, the humanities and arts. We also seek to foster the skills and habits of inquiry necessary for such learning: analytical thought, clear communication, and creative expression. Such an education, we believe, provides a crucial foundation for responsible and effective participation in a complex world.

Program Distribution Requirements for the Humanities and Arts Major

REQUIREMENTS	MINIMUM UNITS
1. Humanities and Arts (including MQP) (Note 1)	6
2. Mathematics and Science (Note 2)	2
3. Electives (Note 3)	2

NOTES:

1. Humanities and Arts majors may choose to complete 2 units of work and an MQP in one of the following areas of concentration: History, Literature, Music, Philosophy/Religion, Drama/Theatre, Writing and Rhetoric, Art or Art History, German Studies, Hispanic Studies, American Studies, Environmental Studies, or Humanities Studies of Science and Technology. The remaining 3 units of work may be from any area within the Humanities and Arts except that no less than 1 unit should be from an area of Humanities and Arts outside of the area of the student's main concentration.
2. Must include 2/3 units in mathematics and 2/3 units in basic science. The remaining 2/3 unit may be from mathematics, basic science or computer science.
3. May be from any area except Air Force Aerospace Studies, Military Science, or Physical Education. Courses used to satisfy other degree requirements (i.e. the IQP) may not be used to fulfill this requirement.

CONCENTRATIONS FOR HUMANITIES AND ARTS MAJORS

Humanities and Arts majors may focus their studies by choosing a Concentration within a specific area of the Humanities and Arts, or within an interdisciplinary area closely related to the Humanities and Arts. Concentrations within the Humanities and Arts Department comply with WPI's requirements for Concentrations. Students must complete an MQP and two units of integrated study in the area of their Concentration. Concentrations within the Humanities and Arts (History, Literature, Music, Philosophy, Religion, Drama/Theatre, Writing and Rhetoric, Art History, German Studies, Hispanic Studies) require two units of work in an area designated by specific disciplinary course prefixes, as described below. For example, a Concentration in History requires two units of HI courses at the 2000 level or higher and an MQP in history. Concentrations that are interdisciplinary in nature (American Studies, Environmental Studies, and Humanities Studies of Science and Technology) each require that courses be selected from specific lists of designated courses.

All of these Concentrations are excellent preparation for a variety of careers. Graduates of the Humanities and Arts major have gone to law, business, and medical schools, as well as to graduate programs in the discipline of their Humanities and Arts concentration. Some graduates have pursued careers as writers, teachers, engineers, or scientists. Other students have found work in the theatre as actors, technicians, or playwrights, or in music as composers or performers. The advantages our graduates find in their pursuit of further study and careers are the advantages of a rigorous study of the liberal arts: a good foundation in our cultural traditions and the cultural diversity of the world, and strong skills in research, analysis, writing, or performance.

In addition, since each Humanities and Arts major completes some technical work, either via the Distribution Requirements or a double major in a technical field, our graduates receive unique preparation as technological humanists. This educational experience gives them a distinct advantage in many fields in which a solid knowledge of engineering or science is increasingly valuable, such as environmental studies, drama/theatre, or business. The Humanities and Arts major equips students with vital general professional skills and with broad cultural and technical perspectives. Our many courses devoted to international issues or to foreign languages and the active involvement of Humanities and Arts faculty in the university's global programs provides superb training for technological humanists interested in international issues. Whatever their specific area of concentration, majors in the Humanities and Arts gain an intellectual curiosity and openness to the diversity of human cultural achievements that will enrich their lives and enhance their careers.

REQUIREMENTS

At least 6 units of work in HUA (see "Note 1" under "Program Distributions Requirements for the Humanities and Arts Major") including the following special requirements for each concentration:

Humanities and Arts with History Concentration
2 units of HI (2000 level or higher) and MQP in History

Humanities and Arts with Literature Concentration
2 units of EN, TH, or RH (2000 level or higher) and MQP in Literature

Humanities and Arts with Music Concentration
2 units of MU (2000 level or higher) and MQP in Music

Humanities and Arts with Philosophy Concentration
2 units of PY (2000 level or higher) and MQP in Philosophy

Humanities and Arts with Religion Concentration
2 units of RE (2000 level or higher) and MQP in Religion

Humanities and Arts with Drama/Theatre Concentration
2 units of TH or EN (2000 level or higher) and MQP in Drama/Theatre

Humanities and Arts with Writing and Rhetoric Concentration
2 units of WR (2000 level or higher) and MQP in Writing and Rhetoric

Humanities and Arts with Art Concentration
2 units of AR or HU and MQP in Art

Humanities and Arts with German Studies Concentration
2 units of GN (2000 level or higher) and MQP in German Studies

Humanities and Arts with Hispanic Studies Concentration
2 units in SP (2000 level or higher) and MQP in Spanish

HUMANITIES AND ARTS WITH AMERICAN STUDIES CONCENTRATION

This interdisciplinary concentration examines American culture from the multiple perspectives of American history, literature, and politics. American Studies at WPI takes advantage of the unparalleled resources at the American Antiquarian Society. American Studies majors (and minors) may earn two-thirds-unit of credit at the 3000-level by being admitted to and completing the competitive AAS fall seminar, which annually accepts twelve Worcester Consortium students. Each spring, HUA faculty publicize the upcoming seminar and endorse WPI applicants. AAS seminars typically enroll two or three students from WPI.

1. 1/3 units: one of the following courses: HU 1411 Introduction to American Studies, EN 1231 Introduction to American Literature, EN 1257 Introduction to African American Literature and Culture, HI 1311 Introduction to American Urban History, HI 1312 Introduction to American Social History, or HI 1314 Introduction to Early American History.
2. 2/3 units from List 1 ("American History")
3. 2/3 units from List 2 ("American Literature")
4. 1/3 units from List 3 ("American Politics, Law, and Policy"). This may not include courses taken to fulfill the Social Science Requirement.
5. MQP in American Studies

List 1. American Antiquarian Society Fall Seminar:
This competitive seminar, open to a limited number of Worcester Consortium students, features a different visiting professor and a new thematic focus each fall. The seminar is equivalent to two courses in American Studies at the 3000-level; the comparable WPI discipline(s) will be determined by the topic of each seminar. To apply, consult a member of the American Studies faculty early in the preceding D-term.

List 2. American History:
HI 2310 Topics in Urban History
HI 2311 American Colonial History
HI 2313 American History, 1789-1877
HI 2314 American History, 1877-1920
HI 2315 The Shaping of Post-1920 America
HI 2316 Twentieth Century American Foreign Relations
HI 2318 Topics in Law, Justice and American Society
HI 2335 Topics in the History of American Science and Technology
HI 2400 Topics in Environmental History
HI 2913 Capitalism and Its Discontents
HI 2930 Topics in Latin American History
HI 3312 Topics in American Social History
HI 3314 The American Revolution
HI 3316 Topics in Twentieth-Century U.S. History
HI 3317 Topics in Environmental History
HI 3334 Topics in the History of American Science and Technology
HI 3344 Pacific Worlds

List 3. American Literature:
EN 2221 American Drama
EN 2234 Modern American Novel
EN 2237 American Literature and the Environment
EN 2271 American Literary Histories
EN 3238 American Authors
EN 3231 Supernatural Literatures
EN 3234 Modern American Poetry
EN 3271 American Literary Topics
SP/ID 3531 Contemporary US Latino Literature & Culture

List 4. American Art/Architecture:
AR 2114 Modern Architecture in the American Era, 1750-2001 and Beyond

List 5. American Music:
MU 2719 Jazz History
MU 2722 History of American Popular Music

List 6. American Philosophy and Religion:
PY/RE 2716 Gender, Race, and Class
*RE 2721 Religion and Culture
*RE 3721 Topics in Religion

List 7. American Politics, Law, and Policy:
GOV 1301 U.S.Government
GOV 1303 American Public Policy
GOV 1310 Law, Courts, and Politics
GOV 2302 Science-Technology Policy
GOV 2310 Constitutional Law

* Check with an American Studies advisor to determine if this course has an American focus in a given term.To facilitate degree audits by the Office of the Registrar, HUA faculty will create a form by which to approve unlisted courses that have significant focus on the U.S.national experience.

HUMANITIES AND ARTS WITH ENVIRONMENTAL STUDIES CONCENTRATION

This interdisciplinary concentration combines course work from the humanities and arts, social sciences, and other areas to examine environmental issues.

1. 3/3 units from List 1 ("Designated Environmental Courses in Humanities")
2. 2/3 units from List 2 ("Related Environmental Courses in Social Sciences"). These may not include courses taken to fulfill the Social Science Requirement.
3. 1/3 units from List 3 ("Environmental Courses in Other Areas")
4. MQP in Environmental Studies

List 1. Designated Environmental Courses in Humanities:
AR 2114 Modern Architecture in the American Age
EN 2237 American Literature and the Environment
HI 1311 Introduction to American Urban History
HI 1350 Introduction to Environmental History
HI 2310 Topics in Urban History
HI 2400 Topics in Environmental History
HI 3317 Topics in Environmental History
HI 3331 Topics in the History of European Science and Technology
HI 3335 Topics in the History of Non-Western Science and Technology
HI 3344 Pacific Worlds
INTL 1100 Introduction to International and Global Studies
PY 2712 Social and Political Philosophy
PY 2713 Bioethics
PY 2717 Philosophy and the Environment
PY 2719 Philosophy of Science
PY/RE 2731 Ethics

List 2. Related Environmental Courses in Social Sciences:
DEV 1200 International Development and Society
DEV 2200 Case Studies in International Development Policy and Engineering
ECON 2117 Environmental Economics
ECON 2125 Development Economics
ENV 1100 Introduction to Environmental Studies
ENV 2201 Planning for Sustainable Communities
ENV 2310 Environmental Governance and Innovation
ENV 2400 Environmental Problems and Human Behavior
ENV 2600 Environmental Problems in the Developing World
ENV 2700 Social Media, Social Movements, and the Environment
ENV 2900 The Green Economy and Models for Alternative Forms of Development
ENV 3100 Adventures in Sustainable Urbanism
ENV 4400 Senior Seminar in Environmnetal Studies
GOV 2312 International Environmental Policy

List 3. Environmental Courses in Other Areas:
BB 2040 Principles of Ecology
CE 3059 Environmental Engineering
CE 3070 Urban and Environmental Planning
CE 3074 Environmental Analysis
CE 4060 Environmental Engineering Laboratory
CE/CHE 4063 Transport & Transformation in the Environment
CHE 3702 Energy Challenges in the 21st Century
CHE 3910 Chemical and Environmental Technology
CHE 3920 Air Quality Management
ES 2800 Environmental Impacts of Engineering Decisions
ME 3422 Environmental Issues and Analysis

HUMANITIES AND ARTS WITH HUMANITIES STUDIES OF SCIENCE AND TECHNOLOGY CONCENTRATION

This interdisciplinary concentration enables students to apply the methods of the humanities and social sciences to the study of science and technology.

1. 2/3 units from List 1 ("Designated HSST Courses")
2. 2/3 units from List 1 or List 2 ("Closely Related Courses in Humanities")
3. 2/3 units from List 3 ("Science-Technology-Studies Courses in Other Areas"). These may not include courses taken to fulfill the Social Science Requirement.
4. MQP in Humanities Studies of Science and Technology

List 1: Designated HSST Courses
EN 2252 Science and Scientists in Modern Literature
HI 1330 Introduction to the History of Science and Technology
HI 1350 Introduction to Environmental History
HI 2335 Topics in the History of American Science and Technology
HI 2350 Topics in the History of Science
HI 2400 Topics in Environmental History
HI 2913. Capitalism and Its Discontents
HI 3317 Topics in Environmental History
HI 3331 Topics in the History of European Science and Technology
HI 3334 Topics in the History of American Science and Technology
HI 3335 Topics in the History of Non-Western Science and Technology
PY 2711 Epistemology
PY 2713 Bioethics
PY 2717 Philosophy and the Environment
PY 2719 Philosophy of Science
PY/RE 2732 Suffering, Healing & Values

List 2: Closely Related Courses in Humanities
AR 2114 Modern Architecture in the American Era, 1750-2001 and Beyond
AR 2115 Topics in Architecture since 1960
AR 3112 Modernism, Mass Culture, and the Avant-Garde
HI 1311 Introduction to American Urban History
HI 2310 Topics in Urban History
HI 2315 The Shaping of Post-1920 Amercia
HI 2324 The British Empire
HU 2251 Introduction to Film Studies
HU 2340 Popular Culture and Social Change in Asia
INTL 1100 Introduction to International and Global Studies
INTL 2100 Approaches to Global Studies
INTL 2910 Topics in Global Studies
MU 2300 Foundations of Music Technology
MU/PSY 2501 Music and Mind
RE 2722 Modern Problems of Belief
WR 1011 Writing About Science & Technology
WR 3214 Writing About Disease & Public Health

List 3: Science-Technology-Studies Courses in Other Areas.
AR/ID 3150 Light, Vision and Understanding and the Scientific Community
FY 1100 The Great Problems Seminar
CS 3041 Human-Computer Interactions
CS 3043 Social Implications of Information Processing
DEV 1200 International Development and Society
DEV 2200 Case Studies in International Development Policy and Engineering
ENV 1100 Introduction to Environmental Studies
ENV 2201 Planning for Sustainable Communities
ENV 2310 Environmental Governance and Innovation
ENV 2400 Environmental Problems and Human Behavior
GOV 2302 Science-Technology Policy
GOV 2311 Environmental Policy and Law
GOV 2312 International Environmental Policy
GOV 2314 Cyberlaw and Policy
GOV 2315 Privacy: Laws, Policy, Technology and How They Fit Together
GOV 2319 Global Environmental Politics
IMGD 1000 Critical Studies of Interactive Media and Games
STS 1200 Fundamentals of Global Health
STS 4000 Senior Seminar in Global Public Health

DOUBLE MAJOR IN HUMANITIES AND ARTS

Students may pursue a double major in Humanities and Arts and any area of study at WPI. To pursue the double major, a student must satisfy the degree requirements of both disciplines including an MQP and Distribution Requirements. The double major in Humanities and Arts requires 6 units of studies in the Humanities and Arts, including the MQP and Inquiry Seminar or Practicum. Students interested in pursuing this option should contact Prof. B. Addison, Salisbury Labs, for additional information.

PROFESSIONAL WRITING

DIRECTOR: E.BOUCHER-YIP (HUA)
ASSOCIATE DIRECTOR: K.Lewis (HUA)
ASSOCIATED FACULTY: A. Danielski (HUA), J. deWinter (HUA), B. Faber (HUA & MG), L. Higgins (HUA), S. Lessing (HUA), R. Madan (HUA), A Rivera (HUA), Y. Telliel (HUA)

The goal of the Professional Writing program is to prepare professionals to communicate scientific or technical content to a variety of specialized and non-specialized audiences in useful and accessible ways.

Professional Writing is an interdisciplinary major or double major that combines work in written, oral, visual, and data-based communication with a strong concentration in a scientific or technical field. Students receive individual attention from academic advisors as they design a plan of study that fulfills the program's distribution requirements and best suits their intellectual interests and career aspirations. Majors can select courses and projects in a variety of areas, such as:

- Science writing, medical writing, health communication
- Writing in the public interest, writing for non-profits
- Digital media, visual communication, information design
- Bilingual professional communication, translation

The Professional Writing major provides excellent preparation for students interested in careers in technical and scientific communication, writing and editing, web authoring, information design, public relations, medical writing, translation, and intercultural communication. It prepares students for graduate work. Finally, it prepares professionals in scientific or technical fields to be lead communicators in their careers.

MQP opportunities are available on campus and with local companies, newspapers, public agencies, and private foundations. More information about project and career opportunities for Professional Writing majors can be found on the program website: https://www.wpi.edu/academics/departments/professional-writing.

Program Distribution Requirements for the Professional Writing Major

REQUIREMENTS	MINIMUM UNITS
1. Scientific and/or technical concentration (Note 1)	6
2. Writing and Rhetoric (WR) concentration (Note 2)	3
3. MQP (Note 3)	1

NOTES:

1. The student's scientific and/or technical concentration must be a plan of study, approved by the student's program review committee, with a clear underlying rationale in mathematics, basic science, computer science, engineering, and/or business.
2. The Writing and Rhetoric concentration consists of 3 units from the 2 following categories.
   a. **Writing and Rhetoric (2 units)** from any of the existing WR courses or equivalent ISUs. This must include WR 3112: Rhetorical Theory unless a substitution is authorized by the student's program review committee, which will be granted only under unusual circumstances. No more than one course at the 1000-level can be applied, and students must complete at least one 4000-level course in WR.
   b. **Electives (1 unit)**
   The 1 unit of electives must be coherently defined and approved by the student's program review committee. Students may draw on:

   Courses in Writing and Rhetoric not used to fulfill the above 2 units requirement;

   Courses in science, technology, and culture studies (such as AR/ID 3150, CS 3041, CS 3043, EN 2252, HI 2334, HI 2402, HI 3331, HI 3333, HI 3334, IMGD 2000, IMGD 2001, GOV 2302, PSY 2406;

   Philosophy and ethics courses (such as PY 2711, PY 2713, PY 2714, PY 2716, PY 2717, PY/RE 2718, PY/RE 2731);

   Foreign language courses;

   Business courses (such as BUS 2080, BUS 3010, BUS 4030, OBC 3354, OIE 3420, OBC 4367, MIS 3720, MIS 3787, MIS 4781).
3. The MQP should build on the student's scientific and technical concentration while articulating a problem within professional writing.

HUMANITIES AND ARTS MINORS

Minors can be arranged in areas other than the above. See a professor in the appropriate discipline for further information about minors in other areas and interdisciplinary minors.

AMERICAN STUDIES

The Minor in American Studies is for students who choose to continue their studies in a blend of American history, literature, and other fields beyond the Humanities and Arts Requirement without majoring in American Studies, English, history, or other fields in humanities and arts.

The American Studies Minor consists of a total of two units of coursework in Humanities and Arts that focus on *the national experience of the United States*, distributed in the following way: at least two courses in American history (List 2) and at least two in American literature (List 3), except that HUA 1411 (Introduction to American Studies) may be substituted for either an EN or an HI course. The two units comprising the American Studies Minor must include a minimum of two 3000-level courses and a maximum of one 1000-level course.

American Studies Minors may earn two-thirds-unit of credit at the 3000-level by being admitted to and completing the competitive American Antiquarian Society fall seminar, which annually accepts twelve Worcester Consortium students. Each spring, HUA faculty publicize the upcoming seminar and endorse WPI applicants. AAS seminars typically enroll two or three students from WPI.

No more than one unit of work for the Humanities and Arts Requirement may be applied toward the American Studies Minor. Any student at WPI is eligible to pursue the Minor in American Studies except for students majoring in Humanities and Arts with a concentration in American Studies.

List 1. American Antiquarian Society Fall Seminar:
This competitive seminar, open to a limited number of Worcester Consortium students, features a different visiting professor and a new thematic focus each fall. The seminar is equivalent to two courses in American Studies at the 3000-level; the comparable WPI discipline(s) will be determined by the topic of each seminar. To apply, consult a member of the American Studies faculty early in the preceding D-term.

List 2. American History:
HI 2310 Topics in Urban History
HI 2311 American Colonial History
HI 2313 American History, 1789-1877
HI 2314 American History, 1877-1920
HI 2315 The Shaping of Post-1920 America
HI 2316 Twentieth Century American Foreign Relations
HI 2318 Topics in Law, Justice and American Society
HI 2335 Topics in the History of American Science and Technology
HI 2400 Topics in Environmental History
HI 2401 U.S. Environmental History
HI 2913 Capitalism and Its Discontents
HI 2930 Topics in Latin American History
HI 3312 Topics in American Social History
HI 3314 The American Revolution
HI 3317 Topics in Environmental History
HI 3334 Topics in the History of American Science and Technology
HI 3344 Pacific Worlds

List 3. American Literature:
EN 2221 American Drama
EN 2234 Modern American Novel
EN 2237 American Literature and the Environment
EN 2271 American Literary Histories
EN 3231 Supernatural Literatures
EN 3234 Modern American Poetry
EN 3238 American Authors
EN 3271 American Literary Topics
SP/ID 3531 Contemporary US Latino Literature & Culture

List 4. American Art/Architecture:
AR 2114 Modern Architecture in the American Era, 1750-2001 and Beyond

List 5. American Music:
MU 2719 Jazz History
MU 2722 History of American Popular Music

List 6. American Philosophy and Religion:
PY/RE 2716 Gender, Race, and Class
*RE 2721 Religion and Culture
*RE 3721 Topics in Religion

List 7. American Politics, Law, and Policy:
GOV 1301 U.S.Government
GOV 1303 American Public Policy
GOV 1310 Law, Courts, and Politics
GOV 2302 Science-Technology Policy
GOV 2310 Constitutional Law
GOV 2311 Environmental Policy and Law
GOV 2313 Intellectual Property Law
GOV 2314 Cyberlaw and Policy
GOV 2315 Privacy
GOV 2320 Constitutional Law: Civil Rights and Liberties

* Check with an American Studies advisor to determine if this course has an American focus in a given term.To facilitate degree audits by the Office of the Registrar, HUA faculty will create a form by which to approve unlisted courses that have significant focus on the U.S.national experience.

CHINESE STUDIES

The minor in Chinese Studies offers students the opportunity to extend their study of China and the Chinese Language beyond the Humanities and Arts Requirement. The Chinese Studies minor includes intermediate or above language proficiency and content courses on Chinese history, philosophy, environmental, and society and culture. The minor is primarily intended for non-native speakers of Mandarin Chinese. Native speakers of Mandarin are not eligible to take Chinese language courses at WPI. Native speakers who wish to pursue this minor through content courses need to receive permission from the minor advisor and will most likely have to take advantage of both WPI and Consortium offerings.

Students must demonstrate a level of Chinese proficiency of at least CN 2544 or its equivalent. A total of two units (six courses) are required for the minor degree requirement from the courses listed below. These consist of:

1. No more than 1 unit (3 courses) of intermediate to advanced Chinese language classes chosen from the following list:

   CN 2542 (Cat. I)
   CN 2543 (Cat. I)
   CN 2544 (Cat. I)
   CN 3541 (Cat. I)
   CN 3542 (Cat. I)
   CN 3543 (Cat. I)
   or Consortium courses in Chinese approved by a WPI China faculty member.

2. At least 2/3 unit (2 courses) of advanced culture or society courses chosen from the following list. At least one of these must be at the 3000 level.

   CN 3541 (2nd year Chinese, 4th term, formerly CN 250X) (Cat. I)
   HI 2328 (History of Revolutions in the 20th Century) (Cat. II)
   HI 2343 (East Asia: China at the Center) (Cat. II)
   HU 2340 (Popular Culture and Social Change in Asia: China) (Cat. II)
   HI 3335 (Topics in the History of Non-Western Science and Technology) (Cat. II)
   HI 3343 (Topics in Asian History: Reengineering China) (Cat. I)
   ID 2050 for Hong Kong or Hangzhou Project sites (Cat. I)
   RE 2724 (Religions of the East) (Cat. II)
   1/3 unit of Hangzhou or Hong Kong Project Center IQP (Cat. I)
   or Consortium courses approved by a WPI faculty member in Chinese.

3. 1/3 unit of capstone experience (1 course) consisting of an ISU or a 3000-level course in Chinese history, culture, literature, or philosophy identified before the beginning of the term as the capstone by the student and professor. The capstone experience must be the last course completed for the minor.

WPI policy requires that no more than one unit of course work can be double counted toward other degree requirements. Thus, students may count three courses taken to fulfill other degree requirements (such as the Humanities and Arts Requirement or two course requirement in the Social Sciences) toward the minor, provided that one unit of classes taken for the minor do not double-count for another degree requirement. In practical terms, this means that up to 3/3 units from HUA Requirement and 1/3 unit from a China IQP, with a combined total from the two of no more than 3/3 unit, can be applied to the Chinese Studies minor.

A student who uses an upper level Chinese language course as the capstone for an HUA Requirement fulfilled with language courses cannot use that capstone language course as the capstone for the Chinese Studies minor. For students conducting their IQP or MQP in China, the capstone can take the form of an ISU that reflects on their onsite experiences.

Students interested in pursuing the minor should speak with Professor Jennifer Rudolph or Professor Huili Zheng to find out more and to discuss finding a capstone course and any related background courses.

WPI current courses identified as contributing to a Chinese Studies Minor.

Chinese Language:
CN 1541 Elementary Chinese I (Cat. I)
CN 1542 Elementary Chinese II (Cat. I)
CN 1543 Elementary Chinese III (Cat. I)
CN 2541 Intermediate Chinese I (Cat. I)
CN 2542 Intermediate Chinese II (Cat. I)

CN 2543 Intermediate Chinese III (Cat. I)
CN 2544 Intermediate Chinese IV (Cat. I)
CN 3541 Advanced Intermediate Chinese I (Cat. I)
CN 3542 Advanced Intermediate Chinese II (Cat. I)
CN 3543 Advanced Intermediate Chinese III (Cat. I)
or Consortium Chinese courses in Chinese approved by a WPI China faculty member.

China Content courses:

HI 2328 History of Revolutions in the 20th Century (Cat. II)
HI 2341 Contemporary World Issues in Historical Perspective (Cat. II)
HI 2343 East Asia: China at the Center (Cat. II)
HI 3335 Topics in the History of Non-Western Science and Technology (Cat. II)
HI 3343 Topics in Asian History: Reengineering China (Cat. I)
HU 1412 Introduction to Asia (Cat. I)
HU 2340 Popular Culture and Social Change in Asia: China (Cat. II)
RE 2724 Religions of the East (Cat. II)

DRAMA/THEATRE

The minor in Drama/Theatre is for students who choose to continue their studies in Drama/Theatre beyond the Humanities and Arts Requirement without majoring in Drama/Theatre. Students who, for personal or career purposes, wish to earn official recognition of their achievements in Drama/Theatre, and who do not have academic time to fulfill the requirements for the major, should consider the Drama/Theatre minor.

Because practical experience in performance, including design and production, is an integral component of Drama/Theatre, the requirements for this minor contain a performance emphasis. The Drama/Theatre minor consists of 2 units of work distributed as follows:

1. Drama/Theatre Courses: 4/3 units chosen from among the following:

   EN 1221, EN 1222, EN 2221, EN 2222, EN 2224, EN 3222, EN 3223, EN 3224, or any ISU designated TH.
2. Drama/Theatre Performances: 1/3 unit (at least two 1/6 unit TH ISU, Independent Study).
3. Drama/Theatre Capstone Experience: 1/3 unit Performance Independent Study (EN or TH). The student, with faculty guidance, will perform, design, direct, produce or in some other way create a Drama/Theatre presentation that demonstrates the student's skill and knowledge.

No more than 1 unit of work for the Humanities and Arts Requirement may be applied to the Drama/Theatre minor. The final Inquiry Seminar or Practicum may not be counted toward the minor.

Any student at WPI is eligible to pursue the Minor in Drama/Theatre except for students majoring in Humanities and Arts with a concentration in Drama/Theatre.

ENGLISH

The minor in English is for students who choose to continue their studies in English beyond the Humanities and Arts Requirement without majoring in English. Students who, for personal or career purposes, wish to earn official recognition of their achievements in English, and who do not have academic time to fulfill the requirements for the major, should consider an English minor. Interested students should speak with one of the English faculty in the Department of Humanities and Arts.

The English minor consists of a total of two units of work in English, distributed in the following way:

1. 5/3 units of literature (usually EN) courses, which must include a minimum of one 3000-level course and a maximum of one 1000-level course.
2. 1/3 unit English Capstone Experience. This can be either a 1/3 unit Independent Study in English or a 3000-level course approved by the student and advisor.

No more than one unit of work for the Humanities and Arts Requirement may be applied toward the English minor. Any student at WPI is eligible to pursue the Minor in English except for students majoring in Humanities and Arts with a concentration in Literature.

LANGUAGE (GERMAN OR SPANISH)

The minor in Language can be completed in either German or Spanish. It allows students who are well prepared to continue their study of the language and its culture well beyond the advanced level. The minor consists of a total of two units of work, distributed in the following way:

1. 1 unit of intermediate and advanced language courses in Spanish or German chosen from the following:
   - SP 2522, SP 3521, SP 3522, or higher or
   - GN 2512, GN 3511, GN 3512, or higher.

   (This unit may be double-counted toward the Humanities and Arts Requirement. No more than one unit may be double-counted in this way.)
2. 2/3 unit of advanced literature and culture courses chosen from the following:
   - SP 3523, SP 3524, SP 3525, SP 3526, or Consortium courses approved by a faculty member in Spanish or
   - GN 3513, GN 3514, or Consortium courses approved by a faculty member in German.
   - Any 3000-level experimental course in GN or SP may also be used.
3. 1/3 unit capstone experience consisting of an ISU written in the foreign language.

(If, in the future, there are enough German and Spanish minors combined, the capstone independent study will be a team-taught seminar in comparative civilization/literature.) Interested students should see the following professors in the Humanities and Arts Department: Prof. Brisson (for German) or Prof. Rivera (for Spanish).

HISTORY

The minor in History offers students the opportunity to extend their study of History beyond the Humanities and Arts Requirement without majoring in History. Students who, for personal or career purposes, wish to earn official recognition of their achievements in History, and who do not have academic time to fulfill the requirements for the major, should consider the History minor. Students interested in declaring a minor should speak with one of the history faculty in the Department of Humanities and Arts. The History minor consists of a total of two units of work in history distributed as follows:

1. 5/3 units of history (HI) courses, which must include a minimum of 1 3000-level course and a maximum of one 1000-level course.
2. 1/3 unit History Capstone Experience. This can be either a 1/3 unit Independent Study in History or a 3000-level HI course identified by the student and instructor as the 3000-level capstone course for the student's program. Inquiry Seminars are not eligible to count as capstone courses for the minor. The capstone course must be taken last.
3. No more than one unit of work for the Humanities and Arts Requirement may be applied toward the History minor. Any student at WPI is eligible to pursue the Minor in History except for students majoring in Humanities and Arts with a concentration in History.

MEDIA ARTS

The Media Arts minor is for students who have a serious interest in multimedia and digital art. The Media Art minor includes a series of courses in visual and graphic arts, animation/film/video, audio arts, critical studies of art, and art history.

A total of six courses are required for the minor degree requirement. These consist of:

1. 1 Unit (3 courses) in visual art production (List 1):
2. 1/3 Unit (1 course) in either visual art (List 1), critical studies in art (List 2), or audio arts directly related to digital media production (List 3).
3. 1/3 Unit (1 course) in Art History (List 4).
4. 1/3 Unit 3000 or higher level visual art course as a final capstone experience (List 5).

WPI minor rules apply in that no more than three courses can be double-counted for any other degree requirement. Any student at WPI is eligible to pursue the minor in Media Arts except for students majoring in IMGD with a concentration in Art.

Students interested in pursuing the minor should speak with an HUA advisor about the rules of pursuing the minor, as well as finding a capstone course and any related background courses.

List 1. Visual Art production:

AR 1100	Essentials of Art
AR 1101	Digital Imaging & Computer Art
AR/IMGD 2101	3D Modeling I
AR/IMGD 2202	Figure Drawing
AR/IMGD 2222	2D Animation I
AR 2301	Graphic Design
AR/IMGD 2333	3D Animation I
AR 2401	Video Production
AR/IMGD 2700	Digital Painting
AR/IMGD 3101	3D Modeling II
AR/IMGD 3200	Interactive Electronic Arts
AR/IMGD 3222	2D Animation II
AR/IMGD 3333	3D Animation II
IMGD 3500	Artistic Game Development I
AR/IMGD 3700	Concept Art & Creative Illustration
IMGD 4500	Artistic Game Development II

List 2. Critical Studies in Art

IMGD 1000	Critical Studies of Interactive Media and Games
IMGD 2001	Philosophy & Ethics of Computer Games
GN 3516	German Film
HU 2251	Introduction to Film Studies
SP 3530	Spanish Film/Media: Cultural Issues
WR 2310	Visual Rhetoric

List 3. Audio Arts

IMGD 2030	Game Audio I
IMGD 3030	Game Audio II
MU 2300	Foundations of Music Technology
MU 2801	Making Music with Machines
MU 3614	Topics in Midi
MU 3615	Topics in Digital Sound
MU 3616	Topics in Interactive Programming
MU 3620	Electronic Music Composition

List 4. Art History

AR 1111	Introduction to Art History
AR 2111	Modern Art
AR 2114	Modern Architecture In the American Era
AR 3112	Modernism, Mass Culture, and the Avant-Garde
AR 3150	Light, Vision and Understanding
HU 2251	Introduction to Film Studies
IMGD 4200	History and Future of Immersive and Interactive Media

List 5. 3000 Level Capstone courses

AR/IMGD 3101	3D Modeling II
AR/IMGD 3200	Interactive Electronic Arts
AR/IMGD 3222	2D Animation II
AR/IMGD 3333	3D Animation II
IMGD 3500	Artistic Game Development I
AR/IMGD 3700	Concept Art & Creative Illustration
IMGD 4500	Artistic Game Development II

MUSIC

The Minor in Music is for students who choose to continue their studies in Music beyond the Humanities and Arts Requirement without pursuing a Concentration in Music. Students who, for personal or career purposes, wish to achieve official recognition of their achievements in Music, yet do not find the time to fulfill the requirements for the Concentration, should consider the Music Minor option. The Music Minor consists of two units of work distributed as follows:

1. 1 2/3 units of music courses.
2. 1/3 unit ISU as a final capstone experience. Students, with faculty guidance, will complete a project which could consist of a paper, composition, arrangement, performance, or other project designed in consultation with the faculty advisor.
3. Students may receive no more than 2/3 units from Music Ensembles (MU 2631, MU 2632, MU 2633, MU2634, MU 2635, MU 2636, MU 2637, MU 2638).

4. If a student completes the Humanities and Arts Requirement in music 1 unit of that work may be applied to the minor except the final Seminar or Practicum.
5. A student who is pursuing a Major in Humanities and Arts with Music as the Concentration cannot also receive a Minor in Music.

PHILOSOPHY AND RELIGION

A Philosophy and Religion Minor requires completion of 2 units of work in Philosophy and Religion distributed as follows:

1. 5/3 unit of PY and/or RE courses, which must include a minimum of one 3000-level course and a maximum of one 1000-level course.
2. 1/3 unit Philosophy and Religion Capstone Experience. This can be either a 1/3 unit Independent Study in Philosophy and Religion or a 2000 or 3000-level course approved by the student and advisor, to which significant extra reading and writing requirements are added. The capstone course must be taken last.

Notes: No more than one unit of work from the Humanities and Arts Requirement may be applied toward the Philosophy and Religion minor. The Inquiry Seminar Project cannot be applied to the Minor. Any student at WPI is eligible to pursue the minor in Philosophy and Religion except for students majoring in Humanities and Arts with a concentration in philosophy.

WRITING AND RHETORIC

The minor in Writing and Rhetoric offers students the opportunity to extend their study of writing and rhetoric beyond the Humanities and Arts Requirement without majoring in either the Writing and Rhetoric concentration in Humanities and Arts or the interdisciplinary Professional Writing program. Students interested in declaring a minor should obtain a minor declaration form so that they are assigned an advisor early in the process. Contact Esther Boucher-Yip (efboucher@wpi.edu) for more information.

The minor consists of two units of work, distributed in the following way:

1. 1/3 unit. Core course in Writing and Rhetoric: WR 3112 or equivalent.
2. 1-1/3 unit. Electives in writing and rhetoric (WR). If there is good reason, and with the approval of the Program Review Committee, electives may also include courses in art history, literature (in English or other languages), and philosophy and religion.
3. 1/3 unit. Capstone course WR 4111 unless an Independent Study (ISU) substitution is authorized by the student's program review committee, and will be granted only under unusual circumstances. Should students receive permission to complete the capstone with an ISU, then those students should submit and have approved a one-page proposal for their capstone to the Program Review Committee the term before they intend to complete it.

No more than 1 unit of course work may be double-counted toward the Humanities and Arts Requirement. Students interested in this area also may wish to consider the major in Professional Writing (see catalog rules for minors).

INTERACTIVE MEDIA & GAME DEVELOPMENT

DIRECTOR: J. DeWINTER (HUA)
ASSOCIATE DIRECTOR: B. MORIARTY (IMGD)
ASSOCIATED FACULTY: E. Agu (CS),S. Barton (HUA), F. Bianchi (HUA), R. Bigonah (HUA), F. Chery (IMGD), M. Claypool (CS), J. deWinter (HUA), J. Forgeng (HUA), E. Gutierrez (HUA), L. Harrison (CS), N. Heffernan (CS), M. Keller (HUA), V.J. Manzo (HUA), B. Moriarty (IMGD), D. O'Donnell (IMGD), E. Ottmar (SSPS), C. Roberts (CS), J. Rosenstock (HUA), J. Sanbonmatsu (HUA), L. Sheldon (IMGD), R. Sutter (IMGD), Y. Telliel (HUA), C. Wills (CS),

PROGRAM EDUCATIONAL OBJECTIVES

The educational objectives of the IMGD program are:

- To prepare students for technical and/or creative roles in the interactive media and game industries.
- To provide a solid base of IMGD-related technical and/or creative expertise, strong written and oral communication skills, and substantial experience in collaborating effectively in multidisciplinary teams.
- To cultivate an understanding of the social and ethical issues relevant to interactive media and games, together with a sense of personal responsibility and professionalism.
- To develop personal traits necessary for continuous career growth, including
  - The ability to integrate theory and practice.
  - The ability to think analytically and critically in order to define, analyze and solve technical and/or creative challenges.
  - The ability to learn new skills in response to evolving technology and a dynamic professional environment.

PROGRAM OUTCOMES

The specific outcomes for the IMGD program are that all graduates will:

1. Demonstrate practical skill and in-depth understanding of IMGD-related technologies, concepts, tools and aesthetics.
2. Have a base of knowledge in computer science, mathematics and the natural/engineering sciences.
3. Have a base of knowledge in IMGD-related design, audio, cultural narratives and visual arts.
4. Be aware of social and philosophical issues pertaining to interactive media and games.
5. Be able to creatively express and analyze artistic forms relative to IMGD.
6. Communicate effectively orally, in writing, and in visual media.
7. Successfully complete individual projects.
8. Successfully complete a group project with students from other IMGD disciplines.
9. Successfully complete team-based, full-term IMGD projects.
10. Successfully complete a team-based, multi-term IMGD project.

INTERACTIVE MEDIA & GAME DEVELOPMENT (BACHELOR OF ARTS)

Distribution Requirements for the IMGD Major

REQUIREMENTS — **MINIMUM UNITS**

IMGD Core — **2/3**
Choose 2/3 units from:
- Critical Studies of Interactive Media & Games (IMGD 1000)
- The Game Development Process (IMGD 1001)
- Storytelling in Interactive Media and Games (IMGD 1002)

IMGD Design — **1/3**
Choose 1/3 unit from:
- Design of Tabletop Strategy Games (IMGD 2500)
- Digital Game Design I (IMGD 2900)
- Digital Game Design II (IMGD 3900)
- History & Future of Immersive & Interactive Media (IMGD 4200 or 5200, but not both)
- Serious Games (IMGD 4600)
- Advanced Storytelling: Quest Logic & Level Design (IMGD 4700)
- Digital Game Design Studio (IMGD 4900)
- Game Design Studio (IMGD 5000)
- Design of Interactive Experiences (IMGD 5300)
- User Experience & Design (MIS 4741)
- User Experience Applications (MIS 583)

IMGD Audio — **1/3**
Choose 1/3 unit from one of:
- Game Audio I (IMGD 2030)
- Game Audio II (IMGD 3030)

IMGD Social & Philosophical Issues — **1/3**
Choose 1/3 unit from:
- Social Issues in Interactive Media & Games (IMGD 2000)
- Philosophy & Ethics of Computer Games (IMGD 2001)

Cultural Narratives — **1/3**
Choose 1/3 unit from any course with an EN, PY or RE prefix

Visual Arts — **1/3**
Choose 1/3 unit from one of:
- Essentials of Art (AR 1100)
- Digital Imaging & Computer Art (AR 1101)
- Graphic Design (AR 2301)

Natural & Engineering Sciences — **2/3**
Choose 1/3 unit from any course with an AE, BB, BME, CHE, CE, CH, ECE, ES, GE, ME, PH or RBE prefix.

General Sciences — **1/3**
Choose 1/3 unit from any course with a CS, MA, AE, BB, BME, CHE, CE, CH, ECE, ES, GE, ME, PH or RBE prefix (except CS 2022 or CS 3043).

Mathematics and Data Analysis — **1/3**
Choose 1/3 unit from:
- Data Analysis for Game Development (IMGD 2905)
- Any course with an MA prefix

Computer Science — **2/3**
Choose 2/3 units from any course with a CS prefix (except CS 2022 or CS 3043).

General IMGD — **8/3**
Choose 8/3 units from any course with an IMGD prefix, which must include:
- 1/3 unit of any 1000+ level IMGD course
- 3/3 unit of any 2000+ level IMGD course
- 2/3 units of any 3000+ level IMGD courses
- 2/3 units of any 4000+ level IMGD courses

IMGD Focus Pair — **2/3**
Choose 2/3 units from one of the following IMGD course pairs:
- **Technical Art**
  - Technical Game Development I & II (IMGD 3000 + 4000)
- **Visual Art**
  - Artistic Game Development I & II (IMGD 3500 + 4500)
- **Design**
  - Digital Game Design II & Digital Game Design Studio (IMGD 3900 + 4900)
- **Writing**
  - Writing Narrative for IMGD & Advanced Storytelling: Quest Logic and Level Design (IMGD/WR 3400 + IMGD 4700)

IMGD Electives — **4/3**
Choose 4/3 units from any courses with an IMGD, AR, EN, WR, MU or CS prefix (except CS 2022 or CS 3043), at least 2/3 of which must be 3000+ level.

Major Qualifying Project — **3/3**

TOTAL DEGREE UNITS — **30/3**

NOTE: IMGD majors may not earn a double major in IMGD Technology.

IMGD BA: Concentrations

Students pursuing the IMGD major may, at their option, choose to focus in one of three topics of concentration:
- Visual Art
- Design
- Technical Art
- Writing

Concentrations are a formal degree designation (noted on a student's transcript), earned by completing a topic-specific selection of 6/3 units drawn from the IMGD Focus Pair and IMGD Electives (see above).

In accordance with WPI policy, a student's contribution to their Major Qualifying Project (MQP) must incorporate substantial content/effort in their area of concentration.

IMGD Visual Art Concentration

Students taking the IMGD Visual Arts Concentration must:
1. Satisfy the 2/3 units IMGD Focus Pair requirement by choosing Artistic Game Development I & II (IMGD 3500 + 4500).
2. Satisfy the 4/3 units IMGD Electives requirement by choosing:
   - 1/3 unit from any of:
     - Essentials of Art (AR 1100)
     - Digital Imaging & Computer Art (AR 1101)
     - Graphic Design (AR 2301)
   - 1/3 unit from any of:
     - Introduction to Art History (AR 1111)
     - Modern Art (AR 2111)
     - Modern Architecture in the American Era (AR 2114)
     - Modernism, Mass Culture & the Avant-Garde (AR 3112)
     - Light, Vision & Understanding (AR 3150)
   - 2/3 units from any of:
     - 3D Modeling II (IMGD/AR 3101)
     - Interactive Electronic Arts (IMGD/AR 3200)
     - 2D Animation II (IMGD/AR 3222)
     - 3D Animation II (IMGD/AR 3333)
     - Concept Art & Creative Illustration (IMGD/AR 3700)
3. Contribute substantially to the visual art aspects of their Major Qualifying Project.

IMGD Design Concentration

Students taking the Design Concentration must:
1. Satisfy the 2/3 units IMGD Focus Pair requirement by choosing Digital Game Design II and Digital Game Design Studio (IMGD 3900 + 4900).

2. Satisfy the 4/3 units IMGD Electives requirement by choosing:
   - 2/3 units from any of:
     - Writing Characters for IMGD (IMGD/WR 2400)
     - Business Writing and Communications (WR 2210)
     - Creative Writing (EN 2219)
     - Visual Rhetoric (WR 2310)
     - Writing Narrative for IMGD (IMGD 3400)
     - Rhetorical Theory (WR 3112)
     - Technical Writing (WR 3210)
     - Advanced Creative Writing (EN 3219)
     - Digital Rhetoric (WR 3310)
     - Other IMGD-related writing courses subject to program approval
   - 2/3 units from any of:
     - History & Future of Immersive & Interactive Media (IMGD 4200 or 5200, but not both)
     - Serious Games (IMGD 4600)
     - Advanced Storytelling: Quest Logic & Level Design (IMGD 4700)
     - User Experience & Design (MIS 4741) or User Experience Applications (MIS 583), but not both
     - Game Design Studio (IMGD 5000)
     - Design of Interactive Experiences (IMGD 5300)
     - Other 3000+ level IMGD-related design courses subject to program approval
3. Contribute substantially to the design aspects of their Major Qualifying Project.

IMGD Technical Art Concentration

Students taking the IMGD Technical Art Concentration must:

1. Satisfy the 2/3 units IMGD Focus Pair requirement by choosing Artistic Game Development I & II (IMGD 3500 + 4500).
2. Satisfy the 4/3 units IMGD Electives requirement by choosing:
   - 1/3 unit from any course with a CS prefix (except CS 2022 or CS 3043).
   - 3/3 units from any of:
     - Technical Art and Character Rigging (IMGD 2048)
     - 3D Modeling II (IMGD/AR 3101)
     - Interactive Electronic Arts (IMGD/AR 3200)
     - 3D Animation II (IMGD/AR 3333)
3. Contribute substantially to the technical art aspects of their Major Qualifying Project.

IMGD Writing Concentration

Students taking the Writing Concentration must:

1. Satisfy the 2/3 units IMGD Focus Pair requirement by choosing Writing Narrative for IMGD & Advanced Storytelling: Quest Logic and Level Design (IMGD/WR 3400 + IMGD 4700)
2. Satisfy the 4/3 units IMGD Electives requirement by choosing:
   - Writing Characters for IMGD (IMGD/WR 2400) (1/3 unit)
   - 3/3 units (including at least 2/3 units at 3000+ level) from any of:
     - Elements of Style (WR 2010)
     - Business Writing and Communications (WR 2210)
     - Introduction to Journalism (WR 2213)
     - Creative Writing (EN 2219)
     - Visual Rhetoric (WR 2310)
     - Rhetorical Theory (WR 3112)
     - Technical Writing (WR 3210)
     - Advanced Creative Writing (EN 3219)
     - Digital Rhetoric (WR 3310)
     - Other IMGD-related writing courses subject to program approval
3. Contribute substantially to the writing aspects of their Major Qualifying Project.

INTERACTIVE MEDIA & GAME DEVELOPMENT TECHNOLOGY (BACHELOR OF SCIENCE)

Distribution Requirements for the IMGD Technology Major

REQUIREMENTS — **MINIMUM UNITS**

IMGD Core — **2/3**

Choose 2/3 units from:
- Critical Studies of Interactive Media & Games (IMGD 1000)
- The Game Development Process (IMGD 1001)
- Storytelling in Interactive Media & Games (IMGD 1002)

IMGD Design — **1/3**

Choose 1/3 unit from:
- Design of Tabletop Strategy Games (IMGD 2500)
- Digital Game Design I (IMGD 2900)
- Digital Game Design II (IMGD 3900)
- History & Future of Immersive & Interactive Media (IMGD 4200 or 5200, but notboth)
- Serious Games (IMGD 4600)
- Advanced Storytelling: Quest Logic & Level Design (IMGD 4700)
- Digital Game Design Studio (IMGD 4900)
- Game Design Studio (IMGD 5000)
- Design of Interactive Experiences (IMGD 5300)
- User Experience & Design (MIS 4741)
- User Experience Applications (MIS 583)

IMGD Audio — **1/3**

Choose 1/3 unit from:
- Game Audio I (IMGD 2030)
- Game Audio II (IMGD 3030)

IMGD Social & Philosophical Issues — **1/3**

Choose 1/3 unit from:
- Social Issues in Interactive Media & Games (IMGD 2000)
- Philosophy & Ethics of Computer Games (IMGD 2001)

Cultural Narratives — **1/3**

Choose 1/3 unit from any course with an EN, PY or RE prefix.

Visual Arts — **1/3**

Choose 1/3 unit from:
- Essentials of Art (AR 1100)
- Digital Imaging and Computer Art (AR 1101)
- Graphic Design (AR 2301)

Natural & Engineering Sciences — **2/3**

Choose 2/3 units from any courses with an AE, BB, BME, CHE, CE, CH, ECE, ES, GE, ME, PH or RBE prefix.

Mathematics and Data Analysis — **2/3**

Choose 2/3 units from:
- Data Analysis for Game Development (IMGD 2905)
- Any courses with an MA prefix

General IMGD — **5/3**

Choose 5/3 units from any courses with an IMGD prefix, which must include:
- 1/3 unit of any 1000+ IMGD course
- 1/3 unit from one of:
  - Novel Interfaces for Interactive Environments (IMGD 3100)
  - Artificial Intelligence for Interactive Media & Games (IMGD/CS 4100)
- Technical Game Development I (IMGD 3000)
- Technical Game Development II (IMGD 4000)
- 1/3 unit of any 4000+ IMGD course

Computer Science — **11/3**

Choose 11/3 units from any courses with a CS prefix, which must include:
- 5/3 units of any CS courses

- Any 3/3 units from:
  - Operating Systems (CS 3013)
  - Human-Computer Interaction (CS 3041)
  - Database Systems I (CS 3431)
  - Computer Networks (CS 3516)
  - Software Engineering (CS 3733)
- Any 3/3 units from:
  - Object-Oriented Analysis & Design (CS 4233)
  - Webware: Computational Technology for Network Information Systems (CS 4241)
  - Introduction to Artificial Intelligence (CS 4341)
  - Data Mining & Knowledge Discovery in Databases (CS 4445)
  - Mobile & Ubiquitous Computing (CS 4518)
  - Computer Graphics (CS 4731)
  - Computer Animation (CS 4732)

Computer Science Notes

1. Only CS 1101, CS 1102 and CS courses at the 2000-level or higher can be counted towards the Computer Science requirements.
2. Only one of CS 1101 and CS 1102 may count towards the Computer Science requirement.
3. Only one of CS 2301 and CS 2303 may count towards the Computer Science requirements.
4. CS 2119 and CS 3043 cannot be chosen to satisfy the Computer Science course requirements.
5. Any AP credits earned in Computer Science cannot be applied to the 30/3 unit distribution requirements of the IMGD BS degree. CS AP credit **can** be applied to the Unrestricted Electives units available outside the degree-specific distribution.

Major Qualifying Project	**3/3**
TOTAL DEGREE UNITS	**30/3**

NOTE: IMGD Technology majors may not earn a double major in IMGD.

MINOR IN INTERACTIVE MEDIA & GAME DEVELOPMENT

The Interactive Media & Game Development Minor is for students who, for personal or career purposes, wish to earn official recognition of their achievements in IMGD, but do not have academic time to fulfill the requirements for the major.

A total of six IMGD courses are required for the Minor degree requirement. This consists of:

Two core IMGD courses from this list:

- IMGD 1000. Critical Studies of Interactive Media and Games
- IMGD 1001. The Game Development Process
- IMGD 1002. Storytelling in Interactive Media and Games

Three additional IMGD courses. If necessary for the academic goals of a student's minor program, and with prior approval of the IMGD Minor Coordinator, may include one course in art history, visual art, creative writing and rhetoric, theatre, or music.

One 3000 or higher level IMGD course as a final capstone.

General WPI rules that apply to the Minor are that at most three courses can be double-counted for any other degree requirement, and the capstone course cannot be a double-counted course.

Students interested in pursuing the Minor should speak with an IMGD advisor about the rules of pursuing the Minor, as well as finding a capstone course and any related background courses.

NOTE: IMGD Technical majors may not earn a minor in IMGD.

INTERDISCIPLINARY AND GLOBAL STUDIES

DEAN: K. J. RISSMILLER
PROFESSORS: S. Strauss, R. F. Vaz
ASSOCIATE PROFESSORS: S. Jiusto, S. Tuler
ASSISTANT PROFESSOR: S. Stanlick
TEACHING PROFESSORS: F. Carrera, D. Golding, C. Peet, R. Traver
ASSOCIATE TEACHING PROFESSORS: M. Belz, C. Dehner, L. Dodson, I. Shockey
ASSISTANT TEACHING PROFESSORS: J. M. Davis, J. Doiron, K. Foo, C. Kurlanska, S. McCauley
INSTRUCTORS/LECTURERS: T. Balistrieri, J. Chiarelli, R. Hersh, L. Roberts

In addition to overseeing the Interactive Qualifying Project (see page 18) and the Global Projects Program (see page 19), the Interdisciplinary and Global Studies Division (IGSD) provides the support structure for students who construct individually-designed (ID) majors which cannot readily be accommodated in traditional academic departments.

ID majors may be defined in any area of study where WPI's academic strengths can support a program of study, and in which career goals exist. Many combinations of technical and non-technical study are possible. Do not be limited by the example given here; if you have questions about what programs at WPI are possible, please see Dean Kent Rissmiller in the FIS to discuss how WPI can assist you in reaching your goals.

PROCEDURE FOR ESTABLISHING AN INTERDISCIPLINARY (INDIVIDUALLY-DESIGNED) MAJOR PROGRAM

Students who wish to pursue an individually-designed major program should first discuss their ideas with their academic advisor. The student should then consult with the dean of the IGSD, who will determine, with the assistance of other members of the faculty, if the proposed program is feasible, and, if it is, arrange for its evaluation.

The following procedures will be followed for feasible programs:

1. The student must submit to the dean of the IGSD an educational program proposal, including a "definition of scope," and a concise statement of the educational goals of the proposed program. Goals (such as graduate school or employment) should be specified very clearly. The proposal must be detailed in terms of anticipated course and project work. The proposal must be submitted no later than one calendar year before the student's expected date of graduation, and normally before the student's third year.
2. The Dean of the Interdisciplinary and Global Studies Division will name a three-member faculty committee, representing those disciplines most involved in the goals of the program, to evaluate the proposal. The committee may request clarification or additional information for its evaluation. The proposal, as finally accepted by the committee and the student, will serve as an informal contract to enable the student to pursue the stated educational goals most effectively.

3. Upon acceptance of the proposal, the student will notify the Office of Academic Advising and the Registrar's Office of the choice of ID (individually-designed) as the designation of major. The IGSD then becomes the student's academic department for purposes of record-keeping.
4. The three-person faculty committee will serve as the student's program advisory committee, and will devise and certify the distribution requirements (up to a limit of 10 units including the MQP) appropriate to the student's program.

INTERDISCIPLINARY MINORS

MINOR IN GLOBAL PUBLIC HEALTH

The minor in Global Public Health offers WPI students an opportunity to explore factors that impact the health of populations around the world. Students interested in the minor should meet with faculty associated with Global Public Health as early as possible in their academic career. They will be assigned a minor advisor after completing a minor declaration form.

The Global Public Health minor consists of two units of work distributed in the following way:

1. 2/3 unit Global Public Health Core courses from this list:
   - STS 1200 Fundamentals of Global Health
   - ID 2100 Disease Detectives: An Introduction to Epidemiology
   - Or an Independent Study (ISU) approved by the Global Public Health Steering Committee
2. 3/3 unit Global Public Health Electives. 2/3 unit of these electives must be at the 2000 level or higher. These may be selected from among global public health related courses in humanities, social sciences, life sciences, engineering or business (see below). These may include:
   - 1/3 unit Great Problems Seminar course (FY 1100) that has a Global Public Health focus and the approval of the Global Public Health Steering Committee
   - any course listed below among Global Public Health electives or courses approved by the Global Public Health Steering Committee.
3. 1/3 unit Senior Seminar in Global Public Health (STS 4000). This seminar may be taken concurrently, or any time after a Global Public Health Experience (for example, a Global Public Health -focused IQP or MQP (see below)). With the approval of the Global Public Health Steering Committee, the seminar may be completed as an independent study.
4. Global Public Health Experience. All Global Public Health minors require an 'experience' in global public health that is educational in nature and equivalent in length to at least one WPI term. Example experiences include global public health related IQPs and MQPs, or activities such as internships, service learning or significant volunteer work accompanied by a reflective writing assignment. The Program Steering Committee Chair must approve this experience, prior to the student undertaking it, by signing the 'Global Public Health Experience Approval' at the bottom of the Application for the Global Public Health Minor.

WPI policy require that no more than one unit of course work can be double counted toward other degree requirements. Thus, students may count three courses for the minor to fulfill other degree requirements as long as one unit of the minor does not double count. In other words, students must take STS 4000 and two other courses for this minor that do not count for another degree requirement.

Global Public Health Minor Electives: Below is a list of examples of relevant courses, which students can choose from to fulfill their Global Public Health elective requirements. Students will take 1 Unit (at least 2 of the 3 courses must be at or above the 2000 level) from the list below or courses approved by the Global Public Health Steering Committee.

Social Science and Policy Study
- GOV 2312 International Environmental Policy
- GOV 2319 Global Environmental Politics
- GOV 2302 Science, Technology, and Policy
- GOV 1320 Topics in International Politics
- SOC 1202 Introduction to Sociology and Cultural Diversity
- ECON 2125 Development Economics
- PSY1400 Introduction to Psychological Sciences
- PSY 1402 Social Psychology
- PSY 2406 Cross Cultural Psychology: Human Behavior in a Global Perspective
- PSY 2407 Psychology of Gender
- PSY 2408 Health Psychology

Life Sciences
- BB 1025 Human Biology
- BB 2003 Microbiology
- BB 3003 Medical Microbiology
- BB 3920 Immunology

Humanities and Arts
- HI 2401 U.S. Environmental History
- HI 2403 Global Environmental History
- INTL 1100 Introduction to International and Global Studies
- PY 2712 Social And Political Philosophy
- PY 2713 Bioethics
- PY 2716 Philosophy of Difference
- PY 2717 Philosophy and the Environment
- PY 3731 Problems in Ethics and Social Philosophy
- PY 2732 Suffering, Healing and Values
- WR 1011 Writing about Science and Technology
- WR 2210 Business Writing and Communication
- WR 3214 Writing about Disease and Public Health

Business
- BUS 1010 Global Environment of Business Decisions
- BUS 1020 Leadership Practice

Other
- CE 3060 Water Treatment
- CE 3061 Wastewater Treatment
- CE 3070 Urban and Environmental Planning
- MA 2610 Applied Statistics for the Life Sciences

MINOR IN NANOSCIENCE

Important to nanoscience are the studies of the structure and function of molecules, and the quantum and atomic properties of matter. Nanoscientists investigate fundamental aspects of the behavior of molecules, materials, devices, and living matter at length scales smaller than the wavelength of visible light. Synthesizing knowledge across disciplines greatly enhances progress in understanding nanoscale systems. A Minor in Nanoscience will benefit students who wish to enhance their disciplinary major with an additional degree designation in the area of Nanoscience.

The Minor in Nanoscience requires the completion of at least two units of course work in the topical areas described below:[a,b] Students planning the minor should contact Professor Burnham in the Physics Department.

1. **Structure of Molecules.** At least one course (1/3 unit) in organic, inorganic, or physical chemistry.
2. **Function of Molecules.** At least one course (1/3 unit) selected from the following list:

BB 1035	Introduction to Biotechnology
BB 2550	Cell Biology
BB 2920	Genetics

3. **Quantum Properties of Matter.** At least one course (1/3 unit) selected from the following list:

CH 3530	Quantum Chemistry
PH 1130	Modern Physics
PH 2501 or 2502	Photonics or Lasers
PH 3401 or 3402	Quantum Mechanics

4. **Atomic Properties of Matter.** At least one course (1/3 unit) selected from the following list:

ES 2001	Introduction to Material Science
ME 4875	Introduction to Nanomaterials and Nanotechnology
PH 3502	Solid State Physics

5. **Nanoscale Fabrication and Characterization.** (No minimum number of required courses.)

CHE/ME 2301	Nanobiotechnology Laboratory Experience
PH 2510	Atomic Force Microscopy

6. **Interdisciplinary Capstone Experience in Nanoscience**. (1/3 unit).
   The capstone experience for the nanoscience minor can be satisfied either by i) an independent study arranged for this purpose as the sixth course in the sequence, or ii) a small project during an existing course, also as the sixth course in the sequence.[c] If the second option is chosen, the student must arrange an interdisciplinary capstone experience with the instructor prior to the start of the course, and the instructor must agree to advise it. In either case, documentation of the capstone is required, prepared in consultation with the independent study advisor or instructor, which incorporates and ties together concepts learned in the nanoscience courses selected. After successful completion of the capstone, the instructor shall notify the student, Professor Burnham in the Physics Department, and the Registrar.

NOTES

a. In keeping with Institute-wide policy for minors, up to three courses may be double-counted for degree requirements (at most 1/3 unit of IQP), no course may be triple-counted, and the capstone experience must be done at the end of the sequence. The Major Qualifying Project (MQP) may not be counted toward activity for Minors.

b. Other courses, including graduate courses, may be used to satisfy the four topic areas with the approval of the Nanoscience Minor Committee.

c. A list of faculty who are willing to advise Nanoscience Capstones or ISUs is given at the bottom of https://www.wpi.edu/academics/study/nanoscience-minor.

MINOR IN SUSTAINABILITY ENGINEERING

This academic minor is intended for students who are interested in gaining knowledge and experience in the principles and practices of engineering design for sustainability, and of the critical role of engineering decisions on the sustainability of the resulting designs. Every engineering discipline impacts the environmental and social sustainability of our planet, and knowledge of the principles of sustainability in engineering design will contribute substantially to professional practice.

While this minor is intended primarily for engineering students, it is open to all students. For non-engineering students the expected background courses may increase the total minor program to more than two units.

Review Committee: The Minor Program Review Committee consists of Profs. John Bergendahl, Robert Krueger, and Steven Van Dessel. The Office of Sustainability, directed by Prof. Paul Mathisen, will assist with oversight of the minor.

Requirements: Candidates for the Sustainability Engineering Minor must meet the following requirements:

1. Complete the Minor Declaration Form available from the Registrar's Office and the Completion Form available from the Office of Sustainability or Sustainability website.
   I. Define a focus for the minor. Some examples are given below but these are not comprehensive. Note that the focus must be distinct from the content of your major and must be supported by the courses in the minor. It is important to select an cohesive set of courses that supports a minor in the focus area.
   II. List the academic activities that will be included in the minor, following the general rules for minors at WPI as well as the rules below.
2. Complete two units of work for the minor, one unit of which may be double counted with other degree requirements.The two units must meet the following requirements:
   I. Must include ES 2800, Environmental Impacts of Engineering Decisions.
   II. May include at most 1/3 U of relevant 1000-level work from the following list (List A):
      - ENV 1100, Introduction to Environmental Studies
      - Relevant GPS FY 1100 credit.

III. Must include 2/3 U of relevant sustainability coursework from the Humanities, Business, and/or SSPS areas. Course options in these areas are as follows (List B):
- ECON 2117, Environmental Economics
- ENV 2201, Planning for Sustainable Communities
- ENV 2400, Environmental Problems and Human Behavior
- ENV 2600, Environmental Problems in the Developing World
- ENV 2700, Social Media, Social Movements, and the Environment
- ENV 4400, Senior Seminar in Environmental Studies
- ETR 2900, Social Entrepreneurship
- GOV 2311, Environmental Policy and Law
- GOV 2312, International Environmental Policy
- GOV 2319, Global Environmental Politics
- HI 2401, U.S. Environmental History
- HI 3317, Topics in Environmental History
- PY 2717, Philosophy and the Environment

IV. Must include at least 2/3 U of course work in engineering from the following list (List C):
- AREN 3003, Principles of HVAC Design for Buildings
- AREN 3024, Building Physics
- AREN 3025, Building Energy Simulation
- CHE 3702, Energy Challenges of the 21st Century
- CHE/CE 4063, Transport and Transformations in the Environment
- CE 3059, Environmental Engineering
- CE 3070, Urban and Environmental Planning
- CE 3074, Environmental Analysis
- ECE 3500, Introduction to Contemporary Electric Power Systems
- ES 2001, Introduction to Materials Science
- ES 3001, Introduction to Thermodynamics
- ES 3003, Heat Transfer
- ME 4422, Design and Optimization of Thermal Systems
- ME 4429, Thermofluid Application and Design
- ME 5105, Renewable Energy

3. To accommodate new sustainability-related courses and independent study and project activities, up to two thirds units may be substituted for the activities listed in items III and IV with the approval of the Sustainability Engineering Minor program review committee. This committee may be contacted through the Registrar or the Director of Sustainability.
4. See the WPI Undergraduate Catalog for additional rules for all minors, in particular that the MQP cannot be used in satisfying any Minor and that at most one unit may be double counted with another degree requirement.

Guidance for Students

Possible Focus Areas (not exhaustive):

The Sustainability Engineering Minor provides students with the opportunity to select a focus area that aligns with the student's area of interest. The following focus areas and sample programs are included to provide some possible options for selecting the activities that compose the two units of credit for the minor, although they are not meant be restrictive in any way.

- Sustainable Engineering in the Developing World
- Climate Change Mitigation and Adaptation
- Engineering Design for Sustainability
- Sustainable Manufacturing
- Clean and Renewable Energy
- Sustainable Engineering Materials
- Resource Recovery and Reuse
- Green Buildings
- Sustainable Water Resources Management
- Planning for Sustainability
- Urban Sustainability

INTERNATIONAL DEVELOPMENT, ENVIRONMENT, AND SUSTAINABILITY (IDEaS)

(BACHELOR OF ARTS DEGREE)

CO-DIRECTORS: L. ELGERT AND L. STODDARD

ASSOCIATED FACULTY: M. Bakermans (BB), C. Brown (SSPS), C. Clark (HUA), J. Doyle (SSPS), K. Foo (IGSD), R. Gottlieb (HUA), R. Krueger (SSPS), C. Kurlanska (IGSD), S. LePage (CEE), J. MacDonald (CBC), P. Mathiesen (CEE), G. Pfeifer (UGS) R. Rao (BB), D. Rosbach (CEE), I. Shockey (IGSD), S. Tuler (IGSD)

MISSION STATEMENT

Our planet faces urgent environmental, social, and technological crises. Because these problems involve peoples, natures, planetary systems, and technologies, we need new scientific and engineering approaches that are informed by the social sciences, humanities, the arts, and people's real lives. We must therefore challenge convention. IDEaS therefore offers a major and minor in Environmental Sustainability Studies. The major can be chosen as a stand- alone course of study or be connected with other degree programs, which could range from chemical engineering, to biology and chemistry, or civil engineering. IDEaS also offers a minor in Science and Engineering for International Development. Either degree option invites students to explore the technical area of their choice: to become competent engineers and scientists. These programs also teach those skills for the future workplace: interdisciplinary collaboration; complex problem solving of socio-technical issues; written and oral communication; and the dexterity and creativity to excel in changing contexts .

EDUCATIONAL OUTCOMES

Graduating Students will:

1. Be able to identify, analyze, and development solutions to environmental and socio-economic problems creatively.
2. Have mastered fundamental concepts and methods of inquiry in their areas of specialization, whether environmental or developmental thought, policy, or methodology.
3. Be able to make connections between disciplines and integrate information from multiple sources.
4. Be aware of how their decision-making processes affect and are affected by other individuals separated across time and space.
5. Be aware of personal, societal, and professional ethical standards.
6. Have interpersonal and communication skills and a professional attitude necessary for a successful career.
7. Understand and employ current technological tools.
8. Have the ability to engage in life-long learning.

MAJOR IN ENVIRONMENTAL AND SUSTAINABILITY STUDIES.

Distribution Requirements

REQUIREMENTS	MINIMUM UNITS
1. Environmental and Sustainability Studies Core (Note 1)	1
2. Mathematics & Basic Science (Note 2)	2 2/3
3. Environmental Science and Engineering (Note 3)	3
4. Basic Social Science and Humanities (Note 4)	1
5. Environmental Social Science or Humanities (Note 5)	2
6. MQP	1
Total	10 2/3

NOTES

1. Only courses with the prefix ENV count toward this requirement. Must include the senior seminar in environmental studies.
2. Must include 2/3 unit of calculus, 1/3 unit of statistics, 2/3 unit of chemistry, and 2/3 unit of biology. May include 1/3 unit of basic engineering with the permission of the Environmental Studies Program Review Committee.
3. All courses with prefixes BB, CE, CH, CHE, ES, GE, and PH may qualify under this requirement. BB courses must be at the 2000 level or higher. Must include 1/3 unit of ecology. Must include 1/3 unit of engineering at the 2000 level or higher. The 3 units of environmental science and engineering courses must be coherently defined and approved by the Environmental Studies Program Review Committee.
4. Must include 1/3 unit of economics, 1/3 unit of public policy or political science, and 1/3 unit of either history or philosophy.
5. Must include 1/3 unit environmental economics, 1/3 unit environmental policy, 1/3 unit environmental philosophy, and 1/3 unit environmental history.

MAJOR QUALIFYING PROJECT (1 UNIT)

The MQP is expected to provide an integrative capstone research experience in Environmental and Sustainability Studies. Several types of MQPs are possible: a research study in a particular science or social science discipline, a holistic examination of an environmental problem from an interdisciplinary perspective, or a philosophical or historical analysis of an environmental issue. WPI faculty from academic disciplines including biology, chemistry, economics, geography, history, philosophy, psychology and public policy are associated with the Environmental Studies program and can advise Environmental Studies MQPs related to their area of expertise.

ENVIRONMENTAL IQP OPPORTUNITIES

WPI students can complete an IQP in a wide variety of areas at the intersection of society and technology, and there is no requirement that Environmental and Sustainability Studies students do an environmentally-related IQP. However, for interested students, numerous opportunities exist for environmental IQPs on campus and at off-campus centers. Many other environmentally themed projects are offered on campus as well. Typical project topics include issues of public health, renewable energy, land conservation, air quality and water quality, urban environments, and environmental justice. In some circumstances students may, with the approval of their IQP advisor, their academic advisor, and the Environmental Studies Program Review Committee, complete additional work on an environmental IQP that qualifies the project to count as an Environmental Studies MQP. However, students must still complete two separate, distinct projects, one IQP and one MQP, to meet the requirements for graduation.

MINOR IN ENVIRONMENTAL AND SUSTAINABILITY STUDIES

Students taking minors in environmental studies are expected to designate a member of the Environmental Studies associated faculty as their SS minor advisor, who will assist them in preparing a program that meets the requirements of the minor. Students can obtain assistance at the Environmental Studies Program office in designating an advisor.

REQUIREMENTS	UNITS
Environmental Studies Core (Note 1)	2/3
Environmental Social Science and Humanities (Note 2)	1
Environmental Studies Capstone (Note 3)	1/3

NOTES

1. Only courses with the prefix ENV count toward this requirement.
2. Students must either select courses for breadth, or they may choose a thematic set of courses for depth. At least two of these courses should be above the 2000 level. Additional ENV courses not counted toward the core requirement may be counted here. Students may substitute up to two courses in environmental science with the approval of the Environmental Studies Program Review Committee.
3. The capstone requirement will normally be met by taking ENV4400, Senior Seminar in Environmental Studies. With the approval of the Program Review Committee, the capstone requirement may also be fulfilled via independent study. Students are also strongly encouraged to do an environmental/sustainability related IQP.

APPROVED SOCIAL SCIENCE AND HUMANITIES COURSES

ECON 2117	Environmental Economics
GOV 2311	Environmental Policy and Law
GOV 2312	International Environmental Policy
PY 2717	Philosophy and the Environment
HI 2401	U. S. Environmental History
ECON 2125	Development Economics
EN 2237	American Literature and the Environment
HI 2351	History of Ecology
HI 3317	Topics in Environmental History
SD 1510	Introduction to System Dynamics Modeling

Two examples of sequences that satisfy the requirements for an ENV minor:

ENV MINOR WITH BREADTH

Environmental Studies Core	2/3
Environmental Studies Capstone	1/3
BB 2040 Ecology	1/3
HI 2401 US Environmental History	1/3
ECON 2117 Environmental Economics	1/3

ENV MINOR WITH DEPTH (SOCIAL SCIENCE)

Environmental Studies Core	2/3
Environmental Studies Capstone	1/3
GOV 2311 Env Law and Policy	1/3
GOV 2312 Intl. Env Law and Policy	1/3
ECON 2117 Environmental Economics	1/3

Many other sequences are possible.

MINOR IN SCIENCE AND ENGINEERING FOR DEVELOPMENT (DEV)

Successful candidates for the DEV Minor must meet the following requirements:

1. Complete two units of work that meet the requirements below.
2. Complete the following three courses:
   - DEV 1200: International Development and Society
   - DEV 2200: Case Studies in International Development Policy and Engineering
   - DEV 4400: Science, Engineering, and Design in International Development
3. Complete one unit of work in courses thematically related from environmental and sustainability studies, economics, system dynamics, psychology, or international dimensions of science technology policy, Foisie Business School, or an approved combination. Two of the three courses must be at the 2000-level or above. Some combinations could include:
   - ENV 2310, ENV 2600, GOV 2319 (Governance)
   - ENV 1100, ENV 2900, ENV 4400 (Environment and Society)
   - ECON 1110, ECON 2117, ECON 2125 (Development Economics)
   - GOV 2302, SD 1510, GOV 2319 (International Political Dynamics)
   - PSY 1400, ENV 2400, PSY 2406 (Psychological Science)
   - ETR 1100, ETR 2900, ETR 4930 (Social Entrepreneurship)
4. Complete approved courses and/or project work that reflect global experience.

Students seeking a DEV Minor should complete this form and submit it to the SSPS office as early in the program of study as possible. The chair of the DEV curriculum committee will be responsible for review and approval of all DEV Minor requests.

WPI policy requires that no more than one unit of course work can be double counted toward other degree requirements.

INTERNATIONAL AND GLOBAL STUDIES

DIRECTOR: P. H. HANSEN

ASSOCIATED FACULTY: W.A.B. Addison (HU), M. Belz (IGSD), E. Boucher-Yip (HU), M. Brahimi (HU), U. Brisson (HU), C. Brown (SSPS), F. Carrera (IGSD), C. Dehner (IGSD), D. DiMassa (HU), H. Droessler (HU), W. Du (HU), L. Elgert (SSPS), M. Elmes (BUS), P. Everett (HU), K. Foo (IGSD), J. Galante (HU), D. Golding (IGSD), P. H. Hansen (HU), R. Hersh (IGSD), S. Jiusto (IGSD), R. Krueger (SSPS), C. Kurlanska (IGSD), S. McCauley (IGSD), A. S. Madan (HU), I. Matos-Nin (HU), R. Moody, (HU), S. Nikitina (HU), O. Pavlov (SSPS), C. Peet (IGSD), G. Pfeifer (HU), M. J. Radzicki (SSPS), K. J. Rissmiller (SSPS), A. Rivera (HU), J. Rudolph (HU), K. Saeed (SSPS), W. San Martin (HU), I. Shockey (IGSD), A. Smith (SSPS), G. Somasse (SSPS), J. Sphar (IGSD), S. Stanlick (IGSD),P. Stapleton (SSPS), E. Stoddard (SSPS), S. Strauss (IGSD), S. Taylor (BUS), Y. Telliel (HU), A. Trapp (BUS), R. Traver (IGSD), S. Tuler (IGSD), R. Vaz (IGSD; ECE)

International and Global Studies prepares men and women for future leadership roles in business, industry, research, government and public affairs. International and Global Studies integrates WPI's international and global courses in the humanities, social sciences and business with its global projects and exchange programs. International and Global Studies courses on-campus prepare students to go abroad. After an experience overseas, students integrate their experiences and explore their career options in a capstone seminar. International and Global Studies at WPI offers a range of options including a minor, major, or double major.

MINOR IN INTERNATIONAL AND GLOBAL STUDIES

The minor in International and Global Studies offers students the opportunity to integrate coursework on campus with a global educational experience. Students interested in the minor should meet with faculty associated with International and Global Studies as early as possible. They will be assigned an advisor after completing a minor declaration form. The International and Global Studies minor consists of two units of work distributed in the following way:

1. 2/3 unit International and Global Core. Any courses with the INTL prefix or courses selected from international and global history or social science courses (see below).
2. 1 unit International and Global Electives. These may be selected from among international and global courses in the humanities, social sciences, or business. These may include:
   - any INTL courses;
   - any international and global history or social science courses (see below);
   - any foreign language courses (e.g. AB, CN, GN, SP);
   - 1/3 unit first-year course (e.g. FY 1100);

- International and global courses in business (e.g. BUS 1020), art history (e.g. AR 1111), literature (e.g. EN 3222), music history (e.g. MU 3001), philosophy (e.g. PY 2716), religion (e.g. RE 2724), and writing, and other courses approved by the Program Review Committee.

Electives may not include the MQP.

3. 1/3 unit Senior Seminar in International and Global Studies (INTL 4100). This seminar may be taken at any time after an International and Global Experience. With the approval of the Program Review Committee, the seminar may be completed via independent study.
4. International and Global Experience. All International and Global Studies minors are required to have a study abroad experience that should be educational in nature and equivalent in length to at least one WPI term. All WPI global projects and exchange programs completed at projects centers outside of the United States meet this requirement. If approved by the Program Review Committee, global projects completed in the United States or international educational programs and/or internships sponsored by other organizations also may satisfy this requirement.

WPI policy requires that no more than one unit of course work can be double counted toward other degree requirements. Thus, students may count three courses for the minor taken to fulfill other degree requirements (such as the Humanities and Arts Requirement or two course requirement in the Social Sciences) as long as one unit of the minor does not double-count. In other words, students must take INTL 4100 and two other courses for this minor that do not count for another degree requirement.

International and Global Humanities and Arts Courses

INTL 1100	Introduction to International and Global Studies
INTL 1300	Introduction to Latin America
INTL 2100	Approaches to Global Studies
INTL 2110	Global Justice
INTL 2310	Modern Latin America
INTL 2410	Modern Africa
INTL 2420	Middle East, North Africa and Mediterranean
INTL 2510	Contemporary Europe: Union and Disunion
INTL 2520	Russia Ready: Language and Cultural Context
INTL 2910	Topics in Global Studies
INTL 3050	Global Re-Entry Seminar
INTL 4100	Senior Seminar in International and Global Studies
HI 1313	US and the World
HI 1322	Introduction to European History
HI 1330	Introduction to the History of Science and Technology
HI 1350	Introduction to Environmental History
HI 2310	Topics in Urban History
HI 2314	American History, 1877-1920
HI 2315	The Shaping of Post-1920 America
HI 2316	Twentieth Century American Foreign Relations
HI 2318	Topics in Law, Justice and American Society
HI 2320	Modern European History
HI 2324	The British Empire
HI 2328	History of Revolutions in the Twentieth Century
HI 2335	Topics in the History of American Science and Technology
HI 2341	Contemporary World Issues in Historical Perspective
HI 2343	East Asia: China at the Center
HI 2350	Topics in the History of Science
HI 2400	Topics in Environmental History
HI 2403	Global Environmental History
HI 2913	Capitalism and its Discontents
HI 2921	Topics in Modern European History
HI 2930	Topics in Latin American History
HI 3316	Topics in Twentieth-Century U.S. History
HI 2217	Topics in Environmental History
HI 3312	Topics in American Social History
HI 3331	Topics in the History of European Science and Technology
HI 3334	Topics in the History of American Science and Technology
HI 3335	Topics in the History of Non-Western Science and Technology
HI 3341	Topics in Imperial and Postcolonial History
HI 3343	Topics in Asian History
HI 3344	Pacific Worlds
HU 1222	Introduction to Medical Humanities
HU 1412	Introduction to Asia
HU 1500	Introduction to Gender, Sexuality and Women's Studies
HU 2222	Topics in Medical Humanities
HU 2340	Popular Culture and Social Change in Asia
HU 2258	World Cinemas
HU 2501	STEM-inism
HU 2502	Global Feminisms
AR 1111	Introduction to Art History
AR 2111	Modern Art
EN 1251	Introduction to Literature
EN 1257	Introduction to African American Literature and Culture
EN 2257	Literature and the Environment
EN 2251	Moral Issues in the Modern Novel
EN 2252	Science and Scientists in Modern Literature
EN 2281	World Literatures
EN 3222	Forms in World Drama
EN 3226	Strange and Strangers
EN 3271	American Literary Topics
ISE 3800	Loaded Language: Discourse and Power in International English
IMGD 2000	Social Issues in Interactive Media and Games
IMGD 2001	Philosophy and Ethics of Computer Games
MU 3001	World Music
PY/RE 1731	Introduction to Philosophy and Religion
PY/RE 2716	Gender, Race, and Class
PY 2712	Social and Political Philosophy
PY 2713	Bioethics
PY 2717	Philosophy and the Environment
PY/RE 2731	Ethics
PY 3711	Topics in Philosophy
RE 2721	Religion and Culture
RE 2722	Modern Problems of Belief
RE 2725	Religious and Spiritual Traditions
RE 3721	Topics in Religion
WR 1011	Writing about Science & Technology
WR 3214	Writing about Disease & Public Health
WR 3300	Cross-Cultural Communication

All Modern Language courses (AB, CN, GN, SP)

International and Global Social Science and Business Courses

DEV 1200	International Development and Society
DEV 2200	Case Studies in International Development Policy and Engineering
DEV 4400	Science, Engineering, and Design in International Development
ECON 1110	Introductory Microeconomics
ECON 1120	Introductory Macroeconomics
ECON 2117	Environmental Economics
ECON 2125	Development Economics
ECON 2126	Public Economics
ECON/ETR 2910	Economics and Entrepreneurship
ENV 1100	Introduction to Environmental Studies
ENV 2201	Planning for Sustainable Communities
ENV 2310	Environmental Governance and Innovation
ENV 2400	Environmental Problems and Human Behavior
ENV 2600	Environmental Problems in the Developing World
ENV 2600	Social Media, Social Movements, and the Environment
ENV 3900	The Green Economy and Models for Alternative Forms of Development
ENV 3100	Adventures in Sustainable Urbanism
GOV 1301	U.S. Government
GOV 1313	American Public Policy
GOV 1310	Law, Courts and Politics
GOV 1320	Topics in International Politics
GOV 2312	International Environmental Policy
GOV 2302	Science-Technology Policy
GOV 2311	Environmental Policy and Law
GOV 2312	International Environmental Policy
GOV 2313	Intellectual Property Law
GOV 2314	Cyberlaw and Policy
GOV 2315	Privacy: Laws, Policy, Technology, and How They Fit Together
GOV 2319	Global Environmental Politics
ID 2050	Social Science Research for the IQP
ID 2100	Disease Detectives: An Introduction to Epidemiology
PSY 1400	Introduction to Psychological Science
PSY 1402	Social Psychology
PSY 2406	Cross-Cultural Psychology: Human Behavior in Global Perspective
PSY 2407	Psychology of Gender
SD 1501	Introduction to Systems Dynamics Modeling
SD 2520	Modeling Economic and Social Systems
SS 1505	Games for Understanding Complexity
SOC 1202	Introduction to Sociology and Cultural Diversity
STS 1200	Fundamentals of Global Health
STS 4000	Senior Seminar in Global Public Health
BUS 1010	Leadership Practice
BUS 1020	Global Environment of Business Decisions
BUS 2020	The Legal Environment of Business Decisions
BUS 3010	Creating Value through Innovation
ETR 1100	Engineering Innovation and Entrepreneurship
ETR 2900	Social Entrepreneurship
ETR 3915	Entrepreneurial Business Models
OBC 3354	Organizational Behavior and Change
OBC 4367	Leadership, Ethics and Social Responsibility

Distribution Requirements for the International and Global Studies Major:

REQUIREMENTS	MINIMUM UNITS
International and Global Core (Note 1)	1
International and Global Fields (Note 2)	4
International and Global Experience (Note 3)	0
Science, Technology, Engineering, Mathematics (Note 4)	2
Electives (Note 5)	2
MQP	1
Total	10

NOTES:

1. Only courses with the prefix INTL count toward this requirement. Must include the senior seminar in international and global studies.
2. International and Global Fields: Majors complete at least one unit of work in each of the following areas. They must also complete at least one additional unit of work in one of these areas, which will be considered their primary field.

   a) History and International and Global Studies. These include any course with the INTL prefix and/or any international and global history course (see list).

   b) Language, Literature, and Culture. These include any course in foreign languages, civilization, and literature offered at WPI (e.g. AB, CN, GN, SP), or in the Consortium with the prior approval of the Program Review Committee; also courses approved by the Program Review Committee in Art History (e.g. AR 1111, AR 3112), English Literature (e.g. EN 2251, EN 3222), Music History (e.g. MU 3001), Philosophy (e.g. PY 2716), Religion (e.g. RE 2724), or Writing. Majors who designate Language, Literature, and Culture as their primary field should take most of their courses in a single discipline or in a coherent program approved by the Program Review Committee.

   c) Social Sciences and Business. These include international and global social sciences courses (see list), international and global courses in business (e.g. BUS 1020), and 1/3 unit of a first-year course (e.g. FY 1100). Students may count courses taken for the two-course requirement in Social Sciences.
3. International Studies majors are required to have a study-abroad experience. (In very unusual cases exceptions may be made to this requirement but only with prior approval of the Director and Program Review Committee). This abroad experience may take the form of a project, exchange, or internship approved by the Program Review Committee. The study-abroad experience should be educational in nature and equivalent in length to at least one WPI term.
4. Must include a minimum of 2/3 units in mathematics or computer science and 2/3 units in natural science or engineering science. The remaining 2/3 units may be from any area of mathematics, computer science, natural science or engineering science. Double majors may count courses taken for their other major.
5. Electives may be from any area except Air Force Aerospace Studies, Military Science or Physical Education. Double-majors may count courses taken for their other major.

DOUBLE MAJOR IN INTERNATIONAL AND GLOBAL STUDIES

Students may pursue a double major in International and Global Studies and any area of study at WPI except a major in Humanities and Arts. To pursue the double major, a student must satisfy all of the degree requirements for both disciplines, including an MQP and Distribution Requirements. The double major in International and Global Studies requires the same distribution of courses as the major and either a second MQP in International and Global Studies or an interdisciplinary MQP that satisfies the requirement of both programs as described on page 12. Double majors are also required to have an International and Global Experience.

INTERNATIONAL AND GLOBAL EXPERIENCES

An International and Global Experience may take the form of an international and global IQP, MQP, Humanities and Arts Inquiry Seminar, internship or exchange program. Students often plan their international and global experience in their Sophomore year. All students are advised to consult the list of projects offered at WPI's Global Project Centers. Each fall, the projects and exchange programs for the following year are widely advertised on campus. For information about student exchange programs, see page 227.

Award-winning projects at WPI are frequently on international topics. International and Global Studies offers the opportunity not only to complete some of the highest quality projects at WPI, but also to offer solutions to some of the most challenging problems in the world.

Students interested in International and Global Studies may ask any member of the Associated Faculty for more information, or they may consult our webpages https://www.wpi.edu/academics/departments/international-global-studies.

LIBERAL ARTS AND ENGINEERING

(BACHELOR OF ARTS DEGREE)

DIRECTOR: L. SCHACHTERLE (HU)

The Director will advise students and will convene faculty to serve as the Liberal Arts and Engineering Program Committee as needed.

MISSION STATEMENT

The goal of the Liberal Arts and Engineering Bachelor of Arts (BA) degree is to provide an opportunity for students who want a broad background in engineering and other disciplines, as preparation for further studies in engineering or in other fields such as medicine, law, public policy, international and global studies, business, or wherever a solid technical background would give them a unique edge. The program is also designed to allow students to transfer to an engineering BS program with minimum loss of time.

For more information, see the Admissions web site at https://www.wpi.edu/academics/departments/liberal-arts-engineering.

PROGRAM EDUCATIONAL OBJECTIVES

The Liberal Arts and Engineering degree recognizes that societal and technological issues are becoming more and more interdependent. Leaders of government, non-profit and for-profit organizations are typically educated in non-engineering disciplines yet increasingly would benefit from a more technological grounding. The Liberal Arts and Engineering major, with its emphasis on problem solving, will prepare students not only for further study in engineering but also for many other high-level careers, such as:

- Law
- Medicine and health care
- Energy policy
- Environmental policy
- Technology policy
- Finance
- Technology management
- International relations
- Public affairs and political service
- Performing arts, especially in music
- Consulting

PROGRAM OUTCOMES

Graduates of the BA in Liberal Arts and Engineering major will have:

a) an ability to formulate and solve problems requiring knowledge of both technological and societal/humanistic needs and constraints

b) an ability to apply, as needed, the relevant fundamentals of mathematics, science, engineering, social sciences, and the humanities to solve such problems

c) an ability to use the techniques, skills, and modern tools necessary for professional practice

d) an ability to function on multi-disciplinary teams

e) an understanding of professional and ethical responsibility

f) an ability to communicate effectively in oral, written and visual modes

g) a recognition of the need for, and ability to engage in, life-long learning, in response to the ever-increasing pace of change affecting societal needs and opportunities

h) the broad education necessary to understand the impact of professional solutions in a societal context, both locally and globally.

Minimum Distribution Requirements

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Basic Sciences (Notes 1, 2)	3
2. Engineering Science and Design (Notes 3, 4, 5)	3
3. Humanities and Arts, Social Science, and Business Topics (Notes 6, 7)	3
4. MQP (Note 8)	1

NOTES:

1. Mathematics must include differential and integral calculus and either probability or statistics.
2. All courses with prefixes BB, CH, PH, or GE count toward this requirement. Must include at least 1/3 Unit each of BB, CH, and PH.
3. Courses with prefixes AREN, BME, CE, CHE, CS, ECE, ES, ME, and RBE are eligible to count toward this requirement. These courses should be thematically related; students must gain approval of their program of study in this area from the Liberal Arts and Engineering Program Committee.
4. Must include either CS 1101 or CS 1102.
5. Must include at least one course in engineering design (such as ECE 2799 or ME 2300), plus at least two other courses with a significant laboratory component (a list of such courses will be maintained by the Liberal Arts and Engineering Program Committee).
6. Must include 2 Units of Humanities and Arts and Social Science. Courses with prefixes AR, HI, MU, PY, RH, WR, IMGD, ECON, GOV, PSY, STS, and SD may be eligible to count toward this requirement. Courses must be selected from areas that strongly complement the practice of engineering, such as the history of technology, ethics, writing and visual rhetoric, economics, society-technology studies, and environmental studies. A list of such courses will be maintained by the Liberal Arts and Engineering Program Committee.

Table 1: BA in Liberal Arts and Engineering

Three (3) examples; others possible

15 Units	ECE Design	Energy and Environment	Engineering and Pre-Law
WPI General Education Institutional Requirements (5 Units)			
1 H&A	HU&A of student's choice	HI 1332	HI 2317
2 H&A	HU&A	HI 2324	EN/WR 2211
3 H&A	HU&A	HI 2331	EN/WR 3214
4 H&A	HU&A	HI 2334	EN/WR 3216
5 H&A	HU&A	HI 3331	RH 3112
6 H&A	HU 3900 or HU 3910	HU 3900 or HU 3910	HU 3900 or HU 3910
7 SS	SS	PSY 1402	SOC 1202
8 SS	SS	SS/ID 2050	GOV 1301
9 PE	PE	PE	PE
10 Free Elective	Free Elective	Free Elective	Free Elective
11 Free Elective	Free Elective	Free Elective	Free Elective
12 Free Elective	Free Elective	Free Elective	Free Elective
13 IQP	IQP	IQP	IQP
14 IQP	IQP	IQP	IQP
15 IQP	IQP	IQP	IQP
Mathematics and Science (3 Units)			
16 Math & Science	MA 1021	MA 1021	MA 1021
17 Math & Science	MA 1022	MA 1022	MA 1022
18 Math & Science	MA 1024	MA 1024	MA 1024
19 Math & Science	MA 2051	MA 2051	MA 2051
20 Math & Science	MA 2611	MA 2611	MA 2611
21 Math & Science	CH 1010	CH 1010	CH 1010
22 Math & Science	PH 1110	CH 1020	BB 1035
23 Math & Science	PH 1120	BB 1002	PH 1110
24 Math & Science	BB 1001	PH 1110	PH 1120
Engineering Studies Cornerstone (3 Units)			
Theme	**ECE**	**Energy**	**Eng Science and Design**
25 Engineering Sci/Des	ECE 2010	ES 3001	ES 1020
26 Engineering Sci/Des	ECE 2019	ES 3003	ES 1310
27 Engineering Sci/Des	ECE 2029	ES 3004	ES 2001
28 Engineering Sci/Des	ECE 2049	ES 2501	ES 2501
29 Engineering Sci/Des	ECE 2112	ECE 2010	ES 2502
30 Engineering Sci/Des	ECE 2201	ECE 2019	ES 2503
31 Engineering Sci/Des	ECE 2311	ECE 3501	ES 3003
32 Engineering Sci/Des	ECE 2799 (design)	ME 2300 (design)	ME 2300 (design)
33 Engineering Sci/Des	CS 1101	CS 1101	CS 1101
Liberal Arts Cornerstone (3 Units)			
Theme	**Social, Humanistic, Business Factors of Design**	**Environment and Policy**	**Pre Law**
34 Liberal Studies	PY 2714 Ethics in the Professions	PY 2717 Phil.&Environ.	GOV 1303 American Pub. Policy
35 Liberal Studies	HI 1332 History of Technology	GOV 2311 Ev. Policy & Law	GOV 1310 Law, Courts, Politics
36 Liberal Studies	HI 3331 Topics in Society/Technology Studies	ENV 2400 Environmental Problems and Human Behavior	GOV 2313 Intellectual Property Law
37 Liberal Studies	GOV 2313 Intellectual Property Law	GOV 2312 International EV Policy	GOV 2314 Cyberlaw and Policy
38 Liberal Studies	GOV 2302 Science and Technology Policy	HI 3333 American Technology Development	GOV 2304 Govt. Decision Making and Admin Law
39 Liberal Studies	GOV 2314 Cyberlaw and Policy	GOV 2302 Science and Technological Policy	
40 Liberal Studies	OIE 2850 Engineering Economics	ENV 1100 Introduction to Environmental Studies	BUS 2020 Legal Environment of Business Decisions
41 Liberal Studies	BUS 2020 Legal Environment of Business Decisions	ENV 2200 Environmental Studies in the Various Disciplines	OIE 2850 Engineering Economics
42 Liberal Studies	ETR 3915 Entrepreneurial Business Models	ENV 4400 Senior Seminar in Environmental Studies	FIN 3300 Finance, Risk Analytics & Technology
MQP – aimed at confluence of engineering and liberal arts cornerstones (1 Unit)			
43 MQP	MQP	MQP	MQP
44 MQP	MQP	MQP	MQP
45 MQP	MQP	MQP	MQP

7. May include up to 1 Unit of Business. All courses with prefixes ACC, BUS, ETR, FIN, MIS, MKT, OIE, and OBC are eligible to count toward this requirement.
8. The MQP provides a capstone experience that builds on both the technical (Engineering Science and Design) and nontechnical (Humanities and Arts, Social Science, and Business Topics) components of the student's particular program. At least one advisor to the MQP must be a member of the Liberal Arts and Engineering Associated Faculty.

PROGRAMS OF STUDY AND RELEVANT COURSES

The Liberal Arts and Engineering program will offer considerable curricular flexibility to accommodate a wide range of student interests, but at the same time will require students to be intentional about developing a coherent program of study consistent with the program's objectives. Academic advising will play an important role in helping students plan their programs.

For more information and advice about the program, contact Prof. Lance Schachterle at les@wpi.edu.

The Engineering Science and Design component of the major (Distribution Requirement 2) must be approved by the Liberal Arts and Engineering Program Committee to ensure that it provides students with a focus in some area of engineering. Guidance and examples will be provided so that students know in advance what types of programs will be approved. The intent is to accommodate creative programs while avoiding programs that lack a coherent theme.

The Social and Humanistic Factors component (see Distribution Requirement 3 and Note 6) should consist of courses that complement engineering and technology to support the educational objectives of the program. The Program Committee will maintain and make available to students and advisors lists of current courses that are acceptable for credit toward this requirement.

MATHEMATICAL SCIENCES

L. CAPOGNA, HEAD; M. BLAIS, ASSOCIATE HEAD

PROFESSORS: L. Capogna, A. Heinricher, M. Humi, C. Larsen, R. Lui, K. Lurie, W. Martin, U. Mosco, B. Nandram, M. Sarkis, B. Servatius, D. Tang, B. Vernescu, S.Weekes

ASSOCIATE PROFESSORS: J. Fehribach, S. Olson, R. Paffenroth, Q. Song, S. Sturm, B. Tilley, D. Volkov, F. Wang, S. Walcott, Z. Wu, J. Zou

ASSISTANT PROFESSORS: A. Arnold, O. Mangoubi, P. O'Cathain, G. Wang, M. Wu, Z. Zhang

PROFESSOR OF PRACTICE: J. Abraham

TEACHING PROFESSOR: J. Goulet

TEACHING ASSOCIATE PROFESSORS: M. Blais, M. Johnson, B. Posterro

TEACHING ASSISTANT PROFESSOR: B. Peiris

SENIOR INSTRUCTOR: T. Doytchinova

RESEARCH PROFESSOR: V. Druskin

RESEARCH ASSOCIATE PROFESSOR: V. Yakovlev

POST-DOCTORAL SCHOLARS: M. Andrei, G. Contador Revetria, C. Mayer, H. Nasralah, X. Ramos Olivé, C. Wei, D. Wright

EMERITUS PROFESSORS: P. Christopher, P. Davis, W. Farr, W. Hardell, J.J. Malone, B. McQuarrie, J. Petrucelli, D. Vermes, H. Walker

ASSOCIATED FACULTY: F. Emdad (CS), G. Sarkozy (CS), A. Trapp (BUS)

MISSION STATEMENT

Recognizing the vital role that mathematical sciences play in today's society, the Mathematical Sciences Department provides leading-edge programs in education, research, and professional training in applied and computational mathematics and statistics. These programs are enhanced and distinguished by project-oriented education and collaborative involvement with industry, national research centers, and the international academic community.

PROGRAM EDUCATIONAL OBJECTIVES

The department's major programs provide students with preparation for effective and successful professional careers in the mathematical sciences, whether in traditional academic pursuits or in the many new career areas available in today's technologically sophisticated, globally interdependent society. Through course work, students acquire a firm grounding in fundamental mathematics and selected areas of emphasis. Projects, which often involve interdisciplinary and industrial applications, offer further opportunities to gain mathematical depth and to develop skills in problem-solving, communication, teamwork, and self-directed learning, together with an understanding of the role of the mathematical sciences in the contemporary world.

PROGRAM OUTCOMES

We expect graduates to:

1. Have a solid knowledge of a broad range of mathematical principles and techniques and the ability to apply them.
2. Be able to read, write, and communicate mathematics inside and outside the discipline.
3. Have the ability to formulate mathematical statements and prove or disprove them.
4. Be able to formulate and investigate mathematical questions and conjectures.
5. Understand fundamental axiom systems and essential definitions and theorems.
6. Be able to formulate and analyze mathematical or statistical models.
7. Have the ability to apply appropriate computational technology to analyze and solve mathematical problems.
8. Be able to learn independently and as part of a team, and to demonstrate a depth of knowledge in at least one area of the mathematical sciences.

The Department of Mathematical Sciences at WPI offers:

- i) the Bachelor of Science degree in Mathematical Sciences;
- ii) the Bachelor of Science degree in Actuarial Mathematics;
- iii) a Minor in Mathematics;
- iv) a Minor in Statistics;
- v) a combined B.S./M.S. degree in Applied Mathematics, Applied Statistics, Industrial Mathematics, or Financial Mathematics.

Program Distribution Requirements for the Mathematical Sciences Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required as follows:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics including MQP (See notes 1-5).	7
2. Basic Science (See note 6).	2/3
3. Computer Science (See note 7).	2/3
4. Additional courses or independent studies from other departments that are related to the student's mathematical program, to be selected from basic science, engineering, computer science or business (see Notes 6-8).	2/3
5. Additional courses or independent studies (except AS, MS, PE courses, and other degree requirements) from any area.	3/3

NOTES:

1. Must include MA 3831 and MA 3832, or their equivalents, at least one of MA 3257, MA 3457, or equivalent, and at least one of MA 3823, MA 3825, or equivalent.
2. Must include at least three of the following: MA 2073, MA 2271, MA 2273, MA 2431, MA 2631, or their equivalents.
3. At least 7/3 units must consist of MA courses at the 3000 level or above (the courses in Note 1 count toward this requirement).
4. May not include both MA 2631 and MA 2621.
5. May not include both MA 2071 and MA 2072.
6. Basic science courses must be chosen from the following disciplines: BB, CH, ES, GE, or PH.
7. CS courses may not include both CS 3043 and CS 2022.
8. Business courses may not include FIN 1250.

PROGRAM IN MATHEMATICAL SCIENCES

PROJECTS

Some of the most active career directions in the mathematical sciences are reflected in the MQP areas around which the department's offerings are organized: Algebraic and Discrete Mathematics, Computational and Applied Analysis, Operations Research, and Probability and Statistics. As early as practical, and certainly no later than the sophomore year, the mathematical sciences major should begin exploring these different areas. The transition courses, MA 2073, 2271, 2273, 2431, and 2631, are specifically designed to introduce the four MQP areas while preparing the student for advanced courses and the MQP. The student should talk to faculty in the student's area of interest to develop and select an MQP and MQP advisor.

While most students choose MQPs in one of the four areas mentioned above, it is possible to design an MQP that does not fit into any one area. In such cases, students will want to take special care to plan their programs carefully with their advisors so that sufficient background is obtained before beginning to do research. Independent studies are a good way for students to learn topics that are not taught in regularly-scheduled courses. Interested students should approach faculty with requests for independent studies.

Through the Center for Industrial Mathematics and Statistics (CIMS), students can use their mathematics and statistics training to work on real-world problems that come from sponsors in industry and finance. More information about industrial MQPs and projects can be found at http://www.wpi.edu/+CIMS.

The following sections contain, for each MQP area:

- A brief description of the area including the kinds of challenges likely to be encountered by MQP students and mathematical scientists working there.
- Courses of interest.

ALGEBRAIC AND DISCRETE MATHEMATICS

Algebraic and discrete mathematics is recognized as an increasingly important and vital area of mathematics. Many of the fundamental ideas of discrete mathematics play an important role in formulating and solving problems in a variety of fields ranging from ecology to computer science. For instance, graph theory has been used to study competition of species in ecosystems, to schedule traffic lights at an intersection, and to synchronize parallel processors in a computer. Coding theory has been applied to problems from the private and public sectors where encoding and decoding information securely is the goal. In turn, the problems to which discrete mathematics is applied often yield new and interesting mathematical questions. The goal of a project in discrete mathematics would be to experience this interaction between theory and application. To begin, a typical project team would assess the current state of a problem and the theory that is relevant. Once this is done, the project team's objective would be to make a contribution to solving the problem by developing new mathematical results.

In working in discrete mathematics, one may be writing algorithms, using the computer as a modeling tool, and using the computer to test conjectures. It is important that a student interested in this area have some computer proficiency. Depending on the project, an understanding of algorithm analysis and computational complexity may be helpful.

Courses of Interest

MA 2271	Graph Theory
MA 2273	Combinatorics
MA 3231	Linear Programming
MA 3233	Discrete Optimization
MA 3823	Group Theory
MA 3825	Rings and Fields
MA 4891	Topics in Mathematics (when appropriate)
CS 2301	Systems Programming for Non-Majors
CS 4120	Analysis of Algorithms
CS 4123	Theory of Computation

COMPUTATIONAL AND APPLIED ANALYSIS

This area of mathematics concerns the modeling and analysis of continuous physical or biological processes that occur frequently in science and engineering. Students interested in this area should have a solid background in analysis which includes the ability to analyze ordinary and partial differential equations through both analytical and computational means.

In most circumstances, an applied mathematician does not work alone but is part of a team consisting of scientists and engineers. The mathematician's responsibility is to formulate a mathematical model from the problem, analyze the model, and then interpret the results in light of the experimental evidence. It is, therefore, important for students to have some experience in mathematical modeling and secure a background in one branch of science or engineering through a carefully planned sequence of courses outside of the department.

With the increase in computational power, many models previously too complicated to be solvable, can now be solved numerically. It is, therefore, recommended that students acquire enough computer proficiency to take advantage of this. Computational skills are important in applied mathematics. Students may learn these skills through various numerical analysis courses offered by the department. An MQP in this area will generally involve the modeling of a real-life problem, analyzing it, and solving it numerically.

Courses of Interest

MA 2251	Vector and Tensor Calculus
MA 2431	Mathematical Modeling with Ordinary Differential Equations
MA 3231	Linear Programming
MA 3257	Numerical Methods for Linear and Nonlinear Systems
MA 3457	Numerical Methods for Calculus and Differential Equations
MA 3471	Advanced Ordinary Differential Equations
MA 3475	Calculus of Variations
MA 4235	Mathematical Optimization
MA 4291	Applicable Complex Variables
MA 4411	Numerical Analysis of Differential Equations
MA 4451	Boundary Value Problems
MA 4473	Partial Differential Equations

OPERATIONS RESEARCH

Operations research is an area of mathematics which seeks to solve complex problems that arise in conducting and coordinating the operations of modern industry and government. Typically, operations research looks for the best or optimal solutions to a given problem. Problems within the scope of

MATHEMATICAL SCIENCES MAJOR PROGRAM CHART

UNIVERSITY REQUIREMENTS	
Minimum Academic Credit	15 Units
Residency	8 Units
Humanities and Arts	2 Units
Interactive Qualifying Project	1 Unit
Major Qualifying Project	1 Unit
Social Science	2/3 Unit
Physical Education	1/3 Unit

FOUNDATION COURSES

INTRODUCTORY COURSES	TRANSITION COURSES (1 Unit Required)	CORE COURSES (4/3 Unit Required)
MA 1021-1024	MA 2073	Both MA 3831 and MA 3832
MA 1020-1120	MA 2271*	One of MA 3257 or MA 3457
MA 1033-1034	MA 2273*	One of MA 3823 or MA 3825*
MA 1971	MA 2431	
MA 2051	MA 2631	
MA 2071 or MA 2072		
MA 2201		
MA 2210		
MA 2251		
MA 2610		
MA 2611		

OTHER MA COURSES TO ATTAIN TOTAL OF 6 UNITS:

ACTUARIAL MATH	ANALYSIS	ALGEBRA	DISCRETE MATH	COMPUTATIONAL MATH	OPERATIONS RESEARCH	STATISTICS/ PROBABILITY
MA 2211	MA 2431	MA 2073	MA 2271*	MA 3257	MA 3231	MA 2612
MA 2212	MA 3471*	MA 3823	MA 2273*	MA 3457	MA 3233*	MA 2621
MA 3212	MA 3475*	MA 3825*	MA 3233*	MA 4411*	MA 4235*	MA 2631
MA 4213	MA 4291				MA 4237*	MA 3627*
MA 4214	MA 4451					MA 3631
MA 4892	MA 4473*					MA 4214*
						MA 4631
						MA 4632
						MA 4635

OTHER REQUIREMENTS	
Computer Science Courses	2/3 Unit

* Category II courses, offered in alternating years.

operations research methods are as diverse as finding the lowest cost school bus routing that still satisfies racial guidelines, deciding whether to build a small plant or a large plant when demand is uncertain, or determining how best to allocate timesharing access in a computer network.

Typically, these problems are solved by creating and then analyzing a mathematical model to determine an optimal strategy for the organization to follow. Often the problem requires a statistical model, and nearly always the analysis - whether optimizing through a set of equations or simulating the behavior of a process - involves the use of a computer. Finally, operations researchers must be able to interpret and apply the results of their analyses in an appropriate manner.

In addition to a solid background in calculus, probability and statistics, and the various operations research areas, prospective operations researchers should be familiar with computer programming and managerial techniques.

Courses of Interest

BUS 2080	Data Analysis for Decision Making
MA 2271	Graph Theory
MA 2273	Combinatorics
MA 3231	Linear Programming
MA 3233	Discrete Optimization
MA 3627	Introduction to the Design and Analysis of Experiments
MA 3631	Mathematical Statistics
MA 4222	Top Algorithms in Applied Mathematics
MA 4235	Mathematical Optimization
MA 4237	Probabilistic Methods in Operations Research
MA 4631	Probability and Mathematical Statistics I
MA 4632	Probability and Mathematical Statistics II
OIE 3460	Simulation Modeling and Analysis
OIE 3510	Stochastic Models

ACTUARIAL MATHEMATICS MAJOR PROGRAM CHART

UNIVERSITY REQUIREMENTS	
Minimum Academic Credit	15 Units
Residency	8 Units
Humanities and Arts	2 Units
Interactive Qualifying Project	1 Unit
Major Qualifying Project	1 Unit
Social Science	2/3 Unit
Physical Education	1/3 Unit

FOUNDATION COURSES

INTRODUCTORY COURSES	TRANSITION COURSES (2/3 Unit Required)	CORE COURSES (4/3 Unit Required)	ACTUARIAL COURSES (4/3 Unit Required)
MA 1021-1024	MA 2073	MA 3631	MA 2212
MA 1033-1034	MA 2271*	Both MA 3831 and MA 3832	MA 3212
MA 1971	MA 2273*	One of MA 3257 or MA 3457	MA 3213
MA 2051	MA 2431		MA 4213
MA 2071 or MA 2072	MA 2631		MA 4214
MA 2201			MA 4892
MA 2210			
MA 2211			
MA 2251			
MA 2611			

OTHER MA COURSES TO ATTAIN TOTAL OF 6 UNITS:

ACTUARIAL MATH	ANALYSIS	ALGEBRA	DISCRETE MATH	COMPUTATIONAL MATH	OPERATIONS RESEARCH	STATISTICS/ PROBABILITY
MA 2211	MA 2431	MA 2073	MA 2271*	MA 3257	MA 3231	MA 2612
MA 2212	MA 3471*	MA 3823*	MA 2273*	MA 3457	MA 3233*	MA 2631
MA 3212	MA 3475*	MA 3825*	MA 3233*	MA 4411*	MA 4235*	MA 3627*
MA 3213	MA 4291				MA 4237*	MA 3631
MA 4213	MA 4451					MA 4214
MA 4214	MA 4473*					MA 4631
MA 4892						MA 4632
						MA 4635

OTHER REQUIREMENTS

Basic Science (2/3 Unit Required)	Computer Science (2/3 Unit Required)	School of Business (4/3 Unit Required)
	Cross-listed classes (e.g. MA 2201/ CS 2022) may only count towards one distribution requirement	

* Category II courses, offered in alternating years.

PROBABILITY AND STATISTICS

In many areas of endeavor, decisions must be made using information which is known only partially or has a degree of uncertainty attached to it. One of the major tasks of the statistician is to provide effective strategies for obtaining the relevant information and for making decisions based on it. Probabilists and statisticians are also deeply involved in stochastic modeling - the development and application of mathematical models of random phenomena. Applications to such areas as medicine, engineering, and finance abound.

Students interested in becoming probabilists or mathematical statisticians should consider additional study in graduate school. While graduate study is an option for students whose goals are to be applied statisticians, there are also career opportunities in business, industry, and government for holders of a Bachelor's degree. More information about careers in statistics can be found at the American Statistical Association's web site http://www.amstat.org/careers.

Students planning on graduate studies in this area would be well advised to consider, in addition to the courses of interest listed below, additional independent study or PQP work in probability and statistics, or some of the department's statistics graduate offerings.

Courses of Interest

MA 2611	Applied Statistics I
MA 2612	Applied Statistics II
MA 2631	Probability Theory
MA 3627	Introduction to the Design and Analysis of Experiments
MA 3631	Mathematical Statistics
MA 4237	Probabilistic Methods in Operations Research
MA 4631	Probability and Mathematical Statistics I
MA 4632	Probability and Mathematical Statistics II
MA 4635	Data Analytics and Statistical Learning

PROGRAM IN ACTUARIAL MATHEMATICS

Actuaries provide financial evaluations of risk that help professionals in the insurance and finance industries, and many in large corporations and government agencies make strategic management decisions. Fellowship in the Society of Actuaries or the Casualty Actuarial Society – achieved by passing a series of examinations – is the most widely accepted standard of professional qualification to practice as an actuary.

WPI's program enables students to take the first steps toward preparing for these exams and introduces these majors to the fundamentals of business and economics.

PROJECTS

Off-campus qualifying projects are regularly done in collaboration with insurance companies, and have in the past been sponsored by Aetna, Blue Cross Blue Shield, Hanover, John Hancock, Sun Life, Travelers and Unum. Visit http://www.wpi.edu/+CIMS. These projects give real-world experience of the actuarial field by having students involved in solving problems faced by professional actuaries. Instead of choosing a project already posed by a company/advisor team, students may instead seek out industry-sponsored projects on their own (often through internship connections) and propose them to a potential faculty advisor. Alternatively, students may choose to complete any other project in mathematics.

Program Distribution Requirements for the Actuarial Mathematics Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required as follows:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics (including MQP) (See notes 1-5)	7
2. Basic Science (See note 6)	2/3
3. Computer Science	2/3
4. Business (See note 7)	4/3
5. Additional courses or independent studies (except AS, MS, PE courses, and other degree requirements) from any area	1/3
6. Acturial Seminar (See note 8)	0/3

NOTES:

1. Must include MA3212, MA3631, MA3831 and MA3832, or their equivalents, and at least one of MA3257, MA3457, or equivalent
2. Must include two of the following: MA 2073, MA 2271, MA 2273, MA 2431, MA 2631, or their equivalents
3. Must include three of the following: MA 2212, MA 3213, MA 4213, MA 4214, MA 4892, or their equivalents
4. May include independent studies directed towards Society of Actuaries exams only if the material was not previously covered in a WPI course
5. May not include both MA 2631 and MA 2621
6. Basic science courses must be chosen from the following disciplines: BB, CH, ES, GE, or PH
7. Business courses must be chosen from courses with any of the following prefixes: ACC, BUS, or FIN. BUS 2060, BUS 2070, and FIN 3300 are recommended.
8. The actuarial seminar is a graduation requirement. Students must complete this seminar in at least four terms while at WPI. Please consult with the actuarial faculty for more details about this requirement.

Students interested in pursuing a degree in Actuarial Mathematics should contact Professor Abraham, the Coordinator of the Actuarial Mathematics Program, as soon as possible.

MINOR IN STATISTICS

Statistical methods are widely used in science, engineering, business, and industry. The Statistics Minor is appropriate for all WPI students with interests in experimental design, data analysis, or statistical modeling. The minor is designed to enable a student to properly design studies and analyze the resulting data, and to evaluate statistical methods used in their field of study. Students should discuss course selections for the minor in advance with a statistics faculty member, who serves as the Minor Advisor. The student must complete the Statistics Minor Program Planning and Approval Form, and have it signed by the Minor Advisor. Students are encouraged to do this as early as possible, but it must be done prior to starting the Capstone. The statistics minor consists of completion of at least 2 units of work, which must consist of:

1. At least 5/3 units of coursework, which must be drawn from the following lists of Foundation and Upper-Level Courses, and which must include successful completion of at least 2/3 units from each list:

Courses for Statistics Minor (5/3 Unit Required)

Foundation Courses (2/3 Unit Required)

MA 2073	Matrices and Linear Algebra II
MA 2611	Applied Statistics I
MA 2612	Applied Statistics II
MA 2631	Probability Theory, or
MA 2621	Probability for Applications

Upper-Level Courses (2/3 Unit Required)

MA 3627	Introduction to the Design and Analysis of Experiments
MA 3631	Mathematical Statistics
MA 4213	Risk Theory
MA 4214	Survival Models
MA 4237	Probabilistic Methods in Operations Research
MA 4631	Probability and Mathematical Statistics I
MA 4632	Probability and Mathematical Statistics II
MA 4635	Data Analytics and Statistical Learning

Any statistics graduate course:
MA 509 or any course numbered MA 540 through MA 559

2. The final 1/3 unit Capstone Experience: The capstone experience may be satisfied by certain 3000-level, 4000-level or graduate courses offered by the department or by a suitable independent study with one of the department's statistics faculty. The Capstone must be approved in advance by having the Capstone instructor sign the Statistics Minor Program Approval Form. After completion of the Capstone Experience, the Statistics Minor Program Planning and Approval Form is submitted to the Mathematical Sciences Program Review Chair for final approval.

For information about the Statistics Minor, see any of the statistics faculty: Professor Buddika Peiris, Balgobin Nandram, Zheyang Wu or Jian Zou.

MINOR IN MATHEMATICS

The Minor in Mathematics consists of the successful completion of at least 2 units of academic activities in mathematical sciences.

Students should discuss course selections for the minor in advance with a member of the mathematical sciences faculty who will serve as the Minor Advisor. The student must complete the Mathematics Minor Program Planning and Approval Form and have it signed by the Minor Advisor. Students are encouraged to do this as early as possible, but it must be done prior to starting the Capstone. The following requirements must be satisfied.

1. At least 5/3 units must be coursework in the Mathematical Sciences Department at the 2000 level or above, of which at least 2/3 units must be upper-level courses, i.e. 3000-level, 4000-level, or graduate mathematics courses. Courses selected at the 2000 level, if any, must include at least one of the following courses:

MA 2073	Matrices and Linear Algebra II
MA 2251	Vector and Tensor Calculus
MA 2271	Graph Theory
MA 2273	Combinatorics
MA 2431	Mathematical Modeling with Ordinary Differential Equations
MA 2631	Probability Theory

2. The final 1/3 unit Capstone Experience: The experience may be satisfied by certain 3000-level, 4000-level or graduate courses offered by the department or by a suitable independent study with a Mathematical Sciences faculty member. The Capstone must be approved in advance by having the Capstone instructor sign the Mathematics Minor Planning and Approval Form. After completion of the Capstone Experience, the Mathematics Minor Program Planning and Approval Form is submitted to the Mathematical Sciences Program Review Chair for final approval.

Here are some examples of 5/3 units of coursework for five thematically-related minors. Other options are available.

Applied Analysis	Computational Analysis	Differential Equations	Discrete Mathematics	Operations Research
MA 2051	MA 2051	MA 2051	MA 2201	MA 2071
MA 2071	MA 2071	MA 2251	MA 2271	MA 2073
MA 2431	MA 2073	MA 3471	MA 2273	MA 3231
MA 3831	MA 3257	MA 4411	MA 3233	MA 3233
MA 3832	MA 3457	MA 4473	MA 533	MA 4235 or MA 4237

For more information about the Mathematics minor, see Professor Fehribach, who is the coordinator for Mathematics minors.

MECHANICAL ENGINEERING

J. YAGOOBI, HEAD

PROFESSORS: D. Apelian, I. Braun, C. A. Brown, M. Demetriou, M. Dimentberg, G. Fischer, C. Furlong, N. A. Gatsonis, S. Guceri, Z. Hou, D. Lados, J. Liang, M. M. Makhlouf, B. Mishra, B. Panchapakesan, B. J. Savilonis, S. Shivkumar, R. D. Sisson, Jr., W. Soboyejo, J. M. Sullivan, Jr., Y. Wang

ASSOCIATE PROFESSORS: H. K. Ault, J. Blandino, R. Cowlagi, C. Demetry, M. Fofana, D. J. Olinger, C. Onal, A. Powell, P. Rao, M. W. Richman, Y. Zhong

ASSISTANT PROFESSORS: D. Cote, J. Jayachandran, N. Karanjgaokar, Z. Li, Y. Liu, S. Narra, Y. Zheng

TEACHING PROFESSORS: M. Bhatia, E. Cobb, R. Daniello, F. Levey, D. Planchard, P. Radhakrishnan, A. Sabuncu, C. Scarpino, J. Stabile, Z. Taillefer, S. Wodin-Schwartz

ASSOCIATE D FA CULTY : N. Bertozzi (RBE), K. Billiar (BME), K. Chen (STEM), N. Dembsey (FPE), M. Emmert (CBC), G. Gaudette (BME), S. Ji (BME), S. Johnson (BUS), R. Konrad (BUS), R. Ludwig (ECE), K. Notarianni (FPE), N. Rahbar (CEE), A. Rangwala (FPE), D. Strong (BUS), B. Tilley (MA), W. Towner (BUS), K. Troy (BME)

EMERITUS PROFESSORS: R. Biederman, J. M. Boyd, A.H. Hoffman, J. A. Mayer, Jr., R. L. Norton, R. J. Pryputniewicz

MISSION STATEMENT

The Mechanical Engineering program at WPI aims to graduate students who have the broad expertise required to confront real world technological issues that arise in our society. Students in the program are educated to apply scientific principles and engineering methods to analyze and design systems, processes, and products that, when engineered properly, improve the quality of our lives. The Mechanical Engineering program is consistent with the WPI philosophy of education, in which each student develops the tools required for self-learning, and the sensibility to consider the impact of technology on society in the decisions they will make as engineering professionals.

PROGRAM EDUCATIONAL OBJECTIVES

The Mechanical Engineering Program seeks to have alumni who:

- are successful professionals because of their mastery of the fundamental engineering sciences, and mechanical engineering and their understanding of design processes.
- are leaders in business and society due to a broad preparation in technology, communication, teamwork, globalization, ethics, business acumen and entrepreneurship.
- will use their understanding of the impact of technology on the safety, health and welfare of the public for the betterment of humankind.

STUDENT OUTCOMES

Graduating students should demonstrate that they attained the following:

- an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
- an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
- an ability to communicate effectively with a range of audiences
- an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
- an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
- an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
- an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Program Distribution Requirements for the Mechanical Engineering Major

The normal period of residency at WPI is 16 terms. In addition to WPI requirements applicable to all students (see page 7), students wishing to receive the ABET-accredited degree designated "Mechanical Engineering" must satisfy certain additional distribution requirements. These requirements apply to 10 units of study in the areas of mathematics, basic science, and engineering science and design as follows:

REQUIREMENTS	MINIMUM UNITS
1. Mathematics and Basic Science (Notes 1, 2).	3 2/3
2. Engineering Science and Design (includes MQP) (Notes 3, 4, 5, 6, 7).	6 1/3

NOTES:

1. Must include a minimum of 2 units of mathematics, including differential and integral calculus and differential equations, and linear algebra.
2. Must include a minimum of 1/3 unit in chemistry and 2/3 unit in physics, or 1/3 unit in physics and 2/3 unit in chemistry.
3. Must include 1/3 unit in programming
4. Must include 1/3 unit in each of the following: electrical engineering, materials science, and mechanical engineering experimentation.
5. May include 1000 level courses only if designated ES or ME.
6. Must include two stems of coherent course and/or project offerings as noted below in a and b.
   a. A minimum of 4/3 unit of work in thermofluid systems that includes the topics of thermodynamics, fluid mechanics and heat transfer, plus 1/3 unit at or above the 4000 level that integrates thermofluid design.
   b. A minimum of 4/3 unit of work in mechanical systems that includes the topics of statics, stress analysis, and dynamics, plus 1/3 unit at or above the 4000 level that integrates mechanical design.
7. Must include 1/3 unit of Capstone Design Experience.

Each Mechanical Engineering student must complete a Capstone Design experience requirement. This capstone design experience can be partially or fully accomplished by completing a Major Qualifying Project which integrates the past course work and involves significant engineering design. At the time of registration for the MQP, the project advisor will determine whether the MQP will meet the Capstone Design requirement or not. If not, the academic advisor will identify an additional 1/3 unit of course work in the area of thermofluid design (ME 4422, ME 4429) or mechanical design (ME 4320, ME 4322, or ME 4810) to be taken in order to meet the ABET Capstone Design requirement.

MECHANICAL ENGINEERING DEPARTMENT CONCENTRATIONS

BIOMECHANICAL (AULT)

Students blend biology and biotechnology coursework with continuum mechanics, biomechanics, biofluids, and biomedical materials to support their individual interest. MQPs are usually developed jointly with off-campus medical facilities, including the University of Massachusetts Medical Center.

Typically MQP topics include: soft tissue mechanics, flow in constricted blood vessels, joint kinematics, prosthetic devices, sports biomechanics, biomaterials, tissue engineering and rehabilitation.

Biomechanical

Two (2) Biology and Biotechnology (BB) Courses

Select 4

ME 3501	Elementary Continuum Mechanics
ME 3506	Rehabilitation Engineering
ME/BME 4504	Biomechanics
ME/BME 4606	Biofluids
ME/BME 4814	Biomaterials

Any BME course at the 3000-level or higher except BME 3300

** Plus Biomechanical-related MQP*

ENGINEERING MECHANICS (HOU)

Students select courses to develop the ability to construct models to analyze, predict, and test the performance of solid structures, fluids, and composite materials under various situations.

Typical MQP topics include: mechanical vibrations, stress and strain analysis, computer methods in engineering mechanics, finite element analysis, and vibration isolation. Departmental testing facilities and computer and software support are available.

Engineering Mechanics

Select 6

AE 3410	Compressible Fluid Dynamics
ME 3501	Elementary Continuum Mechanics
ME 3506	Rehabilitation Engineering
AE 3602	Incompressible Fluids
AE 3712	Aerospace Structures
ME/BME 4504	Biomechanics
ME 4505	Advanced Dynamics
ME 4506	Mechanical Vibrations
ME 4512	Introduction to the Finite Element Method
AE 5202	Advanced Dynamics

**Plus Engineering Mechanics MQP*

MANUFACTURING (SISSON)

Courses are available to support student interest in manufacturing engineering, computer-aided design, computer-aided manufacturing, robotics, vision systems, and a variety of manufacturing processes. Typical MQPs include: robotics, composite materials, factory automation, materials processing, computercontrolled machining, surface metrology, fixturing, machine dynamics, grinding, precision engineering, prototype manufacturing, and additive manufacturing.

Manufacturing

Select 2

ME 1800	Manufacturing Science Prototyping & Computer Controlled Machining
ME 2820	Materials Processing
ME 4810	Automotive Materials and Process Design
ME 4821	Plastics

Select 2

ES 3011	Control Engineering I
ME 3820	Computer-Aided Manufacturing
ME/RBE 4815	Industrial Robotics

Select 2

BUS 3020	Achieving Effective Operations
OIE 2850	Engineering Economics
OIE 3410	Materials Management in Supply Chains
OIE 3420	Quality Planning, Design and Control

** Plus Manufacturing MQP*

MATERIALS SCIENCE AND ENGINEERING (SISSON)

Students interested in a strong materials science and engineering component can elect course and project activities in metals, ceramics, polymers, and composite materials with laboratory and project experience using facilities in Washburn Shops and Stoddard Laboratories. Typical MQP topics include: materials processing, materials characterization with X-ray diffraction, optical and electron microscopy, computer modeling of properties and processing, mechanical testing and fatigue, biomaterials, recourse recovery and recycling, photovoltaics, electrochemical energy systems (batteries and fuel cells), corrosion, surface engineering and surface metrology. Another option in the materials program is a Minor in Materials Science and Engineering, which is described under Materials Engineering in this catalog.

Materials Science and Engineering

Select 6

ME 2820	Materials Processing
ME 4718	Advanced Materials with Aerospace Applications
ME 4810	Automotive Materials and Process Design
ME 4813	Ceramics and Glasses for Engineering
ME 4814	Biomaterials
ME 4821	Plastics
ME 4832	Corrosion and Corrosion Control
ME 4840	Physical Metallurgy
ME 4875	Introduction to Nanomaterials and Nanotechnology
MTE/ME 5847	Materials for Electrochemical Energy Systems
Any 500-level MTE course	

** Plus Materials Science MQP*

MECHANICAL DESIGN (AULT)

Courses are available to support development of student interest in the design, analysis, and optimization of an assembly of components which produce a machine. Computer-based techniques are widely used in support of these activities.

Typical MQP topics are: optimum design of mechanical elements, stress analysis of machine components, evaluation and design of industrial machine components and systems, robotics, and computer-aided design and synthesis.

Mechanical Design

2 Required

ME 3310	Kinematics of Mechanisms
ME 3320	Design of Machine Elements

Select 4

ES 1310	Computer-Aided Design
ES 3323	Advanced Computer-Aided Design
ME 2300	Introduction to Engineering Design
ME 3311	Dynamics of Mechanisms and Machines
ME 3506	Rehabilitation Engineering
ME 4320	Advanced Engineering Design
ME/RBE 4322	Modeling and Analysis of Mechatronic Systems
ME 4810	Automotive Materials and Process Design
ME/RBE 4815	Industrial Robotics

** Plus Mechanical Design MQP*

ROBOTICS (FISCHER)

Students select courses to give them a solid foundation in the various aspects of robotics, including kinematics and actuators, sensors, and control and computing. In addition to relevant mechanical engineering courses, students can select courses from electrical engineering and computer science.

Typical MQP topics include designing of robots and robotic components, including mobile ground robots, aerial robots and underwater robots, automatic assembly and industrial robotics applications, and development of software and control algorithms for individual robots and robotic swarms.

MECHANICAL ENGINEERING PROGRAM CHART

STUDENTS EARNING A B.S. DEGREE IN MECHANICAL ENGINEERING MUST COMPLETE 15 UNITS OF STUDY, DISTRIBUTED AS FOLLOWS:

4 UNITS OF NON-TECHNICAL ACTIVITIES

2 UNITS HUMANITIES AND ARTS	*See WPI Requirements*
1 UNIT INTERACTIVE QUALIFYING (IQP) PROJECT	*See WPI Requirements*
2/3 UNIT SOCIAL SCIENCE	*See WPI Requirements*
1/3 UNIT PHYSICAL EDUCATION	*See WPI Requirements*

1 UNIT FREE ELECTIVE

1 UNIT FREE ELECTIVE	*See Catalog*

3 2/3 UNITS OF MATHEMATICS (MA) AND BASIC SCIENCE (BB, CH, GE 2341, PH)

2/3 Units
Student Selected Courses from the General Category of Mathematics and/or Basic Science

2 Units
Differential & Integral Calculus, Ordinary Differential Equations, and Linear Algebra

MATHEMATICS	
MA 1021	MA 1023
MA 1022	MA 1024
MA 2051	MA 2071

3/3 Units
One Chemistry and Two Physics, OR One Physics and Two Chemistry

SCIENCE	
CH 1010	CH 1020
PH 1110	PH 1120

6 1/3 UNITS OF MECHANICAL ENGINEERING

4/3 units required	4/3 units required	4/3 units required	1 unit required	4/3 units required
MECHANICAL SYSTEMS	**THERMAL SYSTEMS**	**OTHER COURSES**	**MAJOR QUALIFYING PROJECT (MQP)**	**ELECTIVES**
ES 2501 ES 2502 ES 2503 One of: ME 4320 ME 4322 ME 4810	ES 3001[2] ES 3004 ES 3003 One of: ME 4422 ME 4429	ES 2001 ECE 2010[3] ME 3901 Programming (ME 2312, ME 4512, BME 1004, CS 1101, or CS 1004)		Engineering (Note 1)

Note 1: Elective courses from engineering disciplines may be selected at the 2000 or higher level. They may also include ES and ME courses at the 1000 level.

Note 2: ES 3001 may be replaced by CH 3510 or PH Thermodynamics. If CH or PH is used to cover thermodynamics, this course counts as a science; another engineering elective is then required.

Note 3: ECE 2010 or any ECE course other than ECE 1799.

Robotics

3 Required

RBE 2001	Unified Robotics I
ES 3011	Control Engineering I or ME 3310 Kinematics of Mechanisms
ME/RBE 4322	Modeling and Analysis of Mechatronic Systems or ME/RBE 4815 Industrial Robotics

Select 3

CS 2102	Object-Oriented Design Concepts or CS 2103 Accelerated Object-Oriented Design Concepts
CS 2301	Systems Programming for Non-Majors or CS 2303 Systems Programming Concepts
CS 3733	Software Engineering
CS 4341	Introduction to Artificial Intelligence
ECE 2049	Embedded Computing in Engineering Design
ECE 2311	Continuous-Time Signal and System Analysis
ECE 2312	Discrete-Time Signal and System Analysis
ECE 4703	Real Time Digital Signal Processing
ES 3011	Control Engineering I (If not selected above)
ES 3323	Advanced Computer-aided Design
ME 3310	Kinematics of Mechanisms (If not selected above)
ME/RBE 4815	Industrial Robotics (If not selected above)
RBE 2002	Unified Robotics II: Sensing
RBE 3001	Unified Robotics III: Manipulation
RBE 3002	Unified Robotics IV: Navigation

**Plus Robotics MQP*

*Others courses with approval from the ME Undergraduate Committee.

THERMAL-FLUID ENGINEERING (YAGOOBI)

Students study the theoretical and empirical bases of thermodynamics, heat transfer, mass transfer, and fluid flow, as well as the application of these fundamental engineering sciences to energy conversion, environmental control, and vehicular systems.

Typical MQPs include: biological fluid mechanics, laminar/turbulent separation, lifting bodies, heat pipes, electronic component cooling, power cycles, thermal-fluid component analysis and design, and energy storage.

Thermal-Fluid Engineering

3 Required

AE 3410	Compressible Fluid Dynamics
ME 3411	Intermediate Fluid Mechanics
ME 4422	Design and Optimization of Thermal Systems
ME 4424	Radiation Heat Transfer Application and Design
ME 4429	Thermodynamic Applications
AE 4711	Fundamentals of Air-Breathing Propulsion

Select 3

ES 3002	Mass Transfer
ME 3501	Continuum Mechanics
ME 4422	Design and Optimization of Thermal Systems
ME 4424	Radiation Heat Transfer Application and Design
ME 4429	Thermodynamic Applications
ME 4430	Integrated Thermochemical Design and Analysis
ME/BME 4606	Biofluids
AE 4711	Fundamentals of Air-Breathing Propulsion

** Plus Thermal-Fluids related MQP*

NOTES:

1. A Concentration area requires a 1 unit of MQP in that area.
2. After consultation with their academic advisor, students may petition the M.E. Dept. Curriculum Committee for approval of a Concentration plan at any time, preferably prior to the middle of their Junior Year.

ENHANCED PROGRAMS

BACHELOR/MASTER'S PROGRAM IN MECHANICAL ENGINEERING

Outstanding students are encouraged to combine a master's degree with their undergraduate WPI studies. Details are found in the WPI GRADUATE PROGRAM section of this catalog, and interested students should initiate discussions with their advisor early in their junior year.

COOPERATIVE EDUCATION PROGRAM

The WPI Cooperative Education Program provides an opportunity to integrate "real-world" experience into an educational program. Details are found in the COOPERATIVE EDUCATION PROGRAM section on page 228.

MINOR IN MECHANICAL ENGINEERING

For students who are not ME majors and are interested in broadening their exposure to and understanding of Mechanical Engineering, the ME department offers a Minor.

The Minor in Mechanical Engineering consists of 2 units of work from the lists below:

1. Select at least 4/3 unit from the following: ES 2001, ES 2501, ES 2502, ES 2503, ES 3001, ES 3003, ES 3004, ES 3323, ME 3901
2. Select no more than 1/3 unit from the following: ES 1020, ES 1310, ME 1800.
3. Must include at least 1/3 unit of the following : ME 3310, ME 3320, ME 4320, ME 4322, ME 4422, ME 4424, ME 4429, ME 4505, ME 4506, ME 4810.

Students seeking an ME Minor should complete an ME-Minor form, available online and at the ME office, and submit it to the ME office as early in the program of study as possible. The chair of the ME Undergraduate Curriculum Committee will be responsible for review and approval of all ME Minor requests.

WPI policy requires that no more than one unit of course work can be double counted toward other degree requirements.

MINOR IN MANUFACTURING ENGINEERING

A minor in Manufacturing Engineering gives students from a variety of majors the opportunity to strengthen their academic preparation and attractiveness to industry, while better preparing them to solve many of the problems that will challenge them in their careers. Most engineers are involved directly or indirectly with manufacturing or manufacturing principles. Manufacturing expertise is essential to all industrialized, developing and even post industrialized societies. The objective of the minor in manufacturing will be to give the students a solid understanding of the principles of production, processing, manufacturability, and quality that can be applied to a wide variety of products, including non-traditional products, such as software, service and information.

The minor requires the completion of 2 units of work as follows.

I. 1 unit of required course work selected from the following list:

ME 1800	Manufacturing Science Prototyping & Computer Controlled Machining
ME 2820	Materials Processing
ME 3820	Computer-Aided Manufacturing
ES 3011	Control Engineering I

II. 2/3 unit of electives, selected from the following list of courses:

_______	any of the courses above, in I., can count if the other three are completed.
BUS 3020	Achieving Effective Operations
CS 4032/MA 3257	Numerical Methods for Linear and Nonlinear Systems
CS 4341	Introduction to Artificial Intelligence
ES 3323	Advanced Computer Aided Design
ME 3310	Kinematics of Mechanisms
ME/RBE 4815	Industrial Robotics
ME 4821	Plastics
OIE 3420	Quality Planning, Design and Control
MFE 510	Control and Monitoring of Manufacturing Processes
MFE 511	Application of Industrial Robotics
MFE 520	Design and Analysis of Manufacturing Processes
MFE 530	Computer Integrated Manufacturing
MFE 540	Design for Manufacturability

III. 1/3 unit of capstone experience:

RBE/ME 4815	Industrial Robotics
MFE 598	Independent Study Project (this must be approved by the MFE minor program committee)
MFE 510	Control and Monitoring of Manufacturing Processes
MFE 511	Application of Industrial Robotics
MFE 520	Design and Analysis of Manufacturing processes
MFE 530	Computer Integrated Manufacturing
MFE 540	Design for Manufacturability

MATERIALS ENGINEERING

Courses and programs of study in materials engineering are included in the Mechanical Engineering Department (page 102). For advisory information, consult that section of the Undergraduate Catalog or members of the materials section of Mechanical Engineering.

MINOR IN MATERIALS

Material properties, material processing issues, or material costs are the limiting factor in the design or performance of almost all systems around us. Engineers, scientists, and managers in all technological sectors often must make material selection decisions based on a variety of considerations, including properties, performance, environmental impact, and cost. A Minor in Materials, feasible within a 15 unit program of study, will benefit students who wish to enhance their disciplinary major with an additional degree designation in the area of materials.

REQUIREMENTS FOR THE MATERIALS MINOR:
The minor requires the completion of 2 units of work as described below:

1. ES 2001 Introduction to Material Science (1/3 unit)
2. 1-1/3 units of electives, selected from the following list of courses [b,c]:

CE 3026	Materials of Construction
CH 3410	Structure, Bonding, and Reactivity in Inorganic Chemistry
CH 2310	Organic Chemistry I
CH 2320	Organic Chemistry II
CH 2330	Organic Chemistry III
CH 4330	Organic Synthesis
ECE 4904	Semiconductor Devices
ME 2820	Materials Processing
ME/AE 4718	Advanced Materials with Aerospace Applications
ME 4810	Automotive Materials and Process Design
ME 4813	Ceramics and Glasses for Engineering Applications
ME/BME 4814	Biomaterials
ME 4821	Plastics
ME 4832	Corrosion and Corrosion Control
ME 4840	Physical Metallurgy
ME 4875	Introduction to Nanomaterials and Nanotechnology
MTE/ME 5847	Materials for Electrochemical Energy Systems
PH 2510	Atomic Force Microscopy
PH 3502	Solid State Physics

Students who are able to design their undergraduate program of study such that they have sufficient preparation may also use the following graduate courses toward a Materials Minor: all MTE graduate courses; CHE 510 Dynamics of Particulate Systems, CHE 531 Fuel Cell Technology.

3. Capstone Experience (1/3 unit)

   The capstone experience requirement for the Minor in Materials must be satisfied by an upper level course or ISU activity that integrates and synthesizes material processing, structure, and property relationships as they affect performance.

   i) Courses that satisfy the capstone experience requirement currently include ME 4810, ME 4813, ME 4814, and ME 4821. Other courses must be approved in advance by the Program Committee for the Minor in Materials.

   ii) Students may satisfy the capstone experience requirement by completing a 1/3 unit ISU that receives prior approval from the Program Committee for the Minor in Materials. The ISU may, for example, take the form of a laboratory experience or may augment the MQP or IQP, considering in depth the materials issues associated with the project topic (see Note d). An ISU related to the MQP must be distinct from the core 1 unit of the MQP and in most cases would be advised by a faculty member other than the MQP advisor.

NOTES:

a. In accordance with the Institute-wide policy on Minors, academic activities used in satisfying the regular degree requirements may be double-counted toward meeting all but one unit of the Minor requirements (see page 11).

b. Physics ISU courses in Superconductors, Photonics, and Lasers may also be counted toward the Materials Minor. In addition, other new or experimental course offerings in the materials area may be approved by the Materials Minor Program Review Committee.

c. Examples: An ECE major designing an integrated circuit for their MQP might conduct a separate analysis of the materials issues related to heat management in the device as the capstone experience for the Minor in Materials; a ME major specifying a gear in a design MQP might conduct a separate analysis of the material processing, structure, and property issues affecting fatigue life of the gear.

d. In accordance with the Institute-wide policy on Minors, the Major Qualifying Project (MQP) cannot be counted toward activity for a Minor. Therefore, a ME, CHE, or any other major whose MQP is judged to be predominantly in the materials area by the Program Review Committee may not count an extra 1/3 unit augmentation of their MQP as their capstone experience in the Minor.

e. The following faculty serve as the Program Review Committee for the Minor in Materials and will serve as Minor Advisors: Richard Sisson (ME), Chrys Demetry (ME), Tahar El-Korchi (CEE).

MILITARY SCIENCE

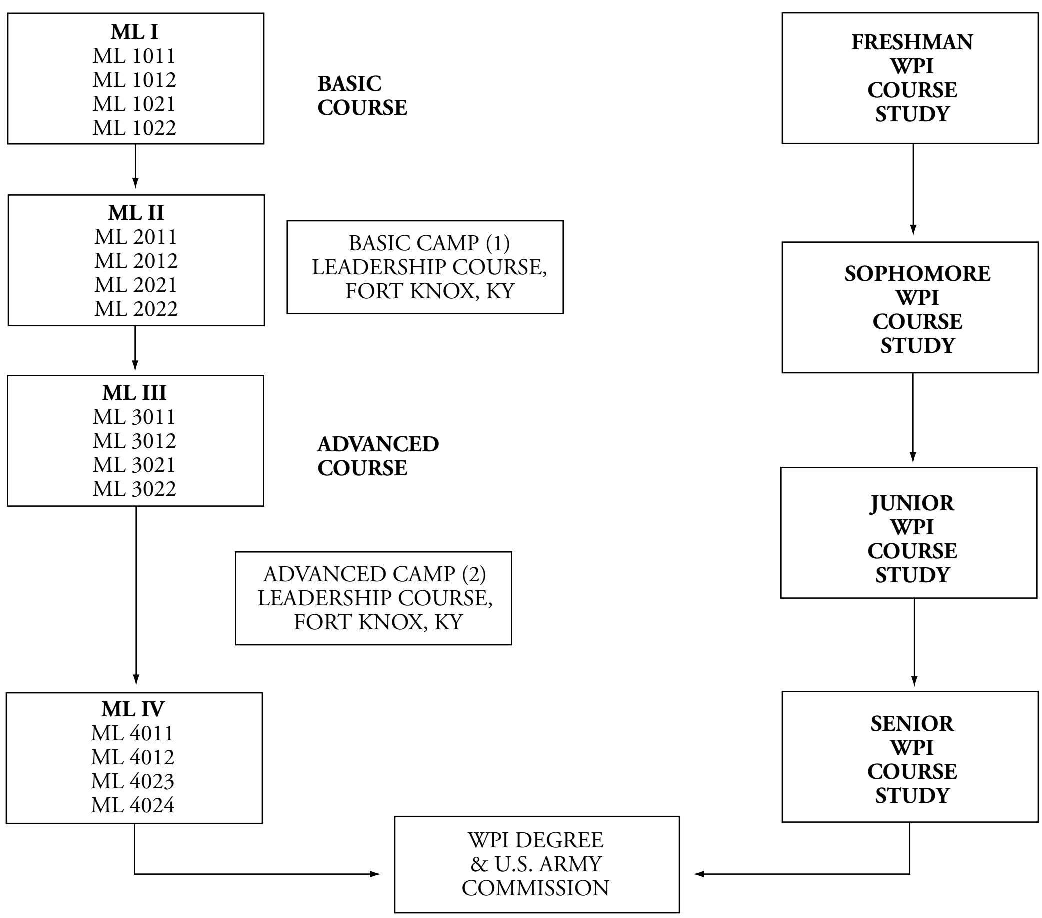
LTC A. D. HEPPE

PROFESSOR: LTC A. D. HEPPE
ASSISTANT PROFESSOR: MAJ M. Liarikos
INSTRUCTORS: MSG A. Sutton, SFC E. Mejia

MISSION STATEMENT:

The Military Science and Leadership Program (Army ROTC) is a premiere leadership program offered by WPI. Open to all students within the Worcester Consortium, the program teaches valuable leadership skills and managerial traits that prepare students for careers in both the private and public sectors. Students partake in hands-on experiences that integrate traditional coursework with innovative training. Students develop strong decision-making and organizational management skills, while cultivating team-building and interpersonal skills, as well as mastering time and stress management techniques.

MILITARY SCIENCE COURSE FLOW CHART



(1) Required for 2 year ROTC program students who did not complete the full Basic Course.
(2) Required attendance for all Juniors and Seniors.

OBJECTIVES AND OUTCOMES:
WPI's Army ROTC prepares multi-faceted future leaders. Students who participate in Army ROTC while pursuing their undergraduate and graduate studies are extremely marketable and highly sought after for their problem-solving and adaptable capabilities. As technology continues to transform organizations and corporations, ROTC students are at the forefront of these cutting-edge developments.

PROGRAM DESCRIPTIONS:
The Military Science and Leadership program is intended to be a four-year program which encourages personal growth and cultivates overall character development.

A. THE BASIC COURSE:
The Basic Course serves as the foundation of the Army ROTC program and is taken over the first two years. The focal points of the Basic Course are leadership, teambuilding and communication skills. Students participate in adventure training (such as orienteering, rappelling and paintball) to put classroom teachings and core concept-strategies to practice.

Students may participate in the first two years of the program commitment free. Students awarded full-tuition scholarships or who participate in the Advanced Course (described below) incur a service obligation and may serve in the Army either full-time or part-time.

B. ADVANCED COURSE:
The Advanced Course is a more intensive leadership program that is taken during the Junior and Senior years, or, during two years of graduate studies. The curriculum continues its focus on problem solving and team building exercises while incorporating military tactics and Ethics.

Student interested in earning a commission as an Army Officer are required to enroll in the Advanced Camp (AC) at Ft Knox, Kentucky. AC is a six-week leadership and tactical course that students are paid to attend during the summer; it is the culmination of the students' training over their tenure on campus. If students decide later in their academic career that they would like to pursue Army ROTC, there are alternate entry options that allow them to receive Basic Course credit and to prepare them for Advanced Camp (1).

Students attending on an Army ROTC Scholarship receive a yearly book-allowance of $1,200 in addition to a monthly stipend. Both "scholarship" and "contracted, non-scholarship" students receive a monthly stipend of $420.00. Students interested in pursuing scholarships or enrolling in the Advanced Course must meet specific eligibility requirements.

PHYSICAL EDUCATION, RECREATION, AND ATHLETICS

D HARMON: DIRECTOR OF PHYSICAL EDUCATION, RECREATION AND ATHLETICS
L MOREAU: DIRECTOR OF PHYSICAL EDUCATION
A MCCARRON: DIRECTOR OF CLUB SPORTS

REQUIREMENTS
Qualification in physical education shall be established by completing 1/3 unit of course work. Students are strongly urged to complete this graduation requirement in their first two years of residency at WPI. Students may take classes multiple times for credit. We do not offer independent study options in Physical Education. In addition to PE 1000-series course offerings, students may satisfy their PE requirement by the following:

1. WPI approved varsity athletic team participation (PE 2000-series). Student must be registered with instructor permission in advance of participation. No retroactive credit will be awarded if failure to register.
2. Club Sports (PE 1200-series). Students must be members of a PE approved club prior to becoming eligible for physical education credit and by meeting established department policies for credit. Students must be registered in advance of participation; no retroactive credit will be awarded if failure to register in advance. Additional fees for some clubs may apply.
3. Approved courses not offered at WPI; advance approval by the Physical Education Department is necessary so students are encouraged to contact the department directly in advance to review. No retroactive credit will be awarded if failure to receive advance approval.
4. Participation in certain ROTC programs may entitle students to a receive PE credit. Students in ROTC programs should review in advance with their respective commanders.

GENERAL PHYSICAL EDUCATION COURSES (PE 1000 SERIES)
This series is offered to provide a variety of courses in the more traditional sport-based area of physical education. These courses can serve the beginner to the more experienced in each activity area. PE 1000 series courses meet twice a week (generally between 8am-5pm) at predetermined times with attendance and participation major factors in a student's final grade.

HEALTHY ALTERNATIVE PHYSICAL EDUCATION COURSES (PE 1099)
These PE courses are offered to provide a variety of wellness, dance and healthy alternatives to traditional PE sport-based classes. These classes are subject to change on a yearly basis in order to provide flexibility in the PE offerings based upon the latest trends in wellness and dance. The focus of these classes is more on individual fitness, wellness and education, with instruction provided to all students in the classes.

THE CLUB SPORTS PROGRAM (PE 1200-SERIES)

The club sports program involves activities in various sports and wellness that are organized and recognized by the Student Government Association as Class II organizations and open to any undergraduate student (more information regarding Club Sports can be found at wpi.edu/+techsync). Students who are properly registered in advance for the club activity in their interest area and who meet the established criteria for participation by the club as well as by PERA department policy, may be eligible for PE course credit. Practice and/or competition times will vary but are generally in the evenings and weekends. Participating students may incur additional fees for equipment, travel, and/or uniforms.

NOTE: Some club sports listed below may not be offered in every academic year.

PE 1201 Club Sport - Alpine Ski Team
PE 1202 Club Sport - Badminton
PE 1203 Club Sport - Ballroom Dancing
PE 1204 Club Sport - Dance Team
PE 1205 Club Sport - Fencing Team
PE 1206 Club Sport - Ice Hockey Team
PE 1207 Club Sport - Karate
PE 1208 Club Sport - Men's Rugby Team
PE 1209 Club Sport - Women's Rugby Team
PE 1210 Club Sport - Men's Ultimate Frisbee Team
PE 1211 Club Sport - Women's Ultimate Frisbee Team
PE 1212 Club Sport - Men's Lacrosse Team
PE 1213 Club Sport - Women's Lacrosse Team
PE 1214 Club Sport - Men's Volleyball Team
PE 1215 Club Sport - Outing: Bouldering
PE 1216 Club Sport - Pep Band
PE 1217 Club Sport - Sailing
PE 1218 Club Sport - Social Dance
PE 1219 Club Sport - Soma: Capoeira
PE 1220 Club Sport - Smas: Boffer Games

ATHLETIC PROGRAMS

THE INTERCOLLEGIATE PROGRAM

The intercollegiate athletics program offers competition in 20 varsity sports.

WPI has excellent facilities and provides the best in protective equipment but, if an injury should occur, a team physician and full-time trainers are available, offering the latest treatment methods and facilities.

Practices are normally held daily, after 4 pm. Midweek contests involving travel are held to a minimum to avoid missing classes. Every effort is made to avoid conflicts with academic activities, and competitions are generally scheduled with schools with similar standards and objectives.

In recent years, teams and individuals have been sent to regional and national tournaments to allow them to compete at the highest possible level. All-America recognition has been attained recently in football, men's soccer, track and field, and wrestling.

THE VARSITY ATHLETICS PROGRAM (PE 2000-SERIES)

The WPI varsity athletics program is a highly involved and competitive program offered in 18 intercollegiate sports. Participants in these activities are selected by the head coach and must have prior approval to register. Practices are held daily in the evenings with contests mid-week and weekends for a period of 18/19 weeks. Every effort is made to avoid conflicts with academic activities and competitions are generally scheduled against schools with similar standards and objectives.

PE 2001 Varsity Football Team
PE 2002 Varsity Men's Soccer Team
PE 2003 Varsity Women's Soccer Team
PE 2004 Varsity Field Hockey Team
PE 2005 Varsity Women's Volleyball Team
PE 2006 Varsity Men's & Women' Cross Country Team
PE 2007 Varsity Wrestling Team
PE 2008 Varsity Men's Basketball Team
PE 2009 Varsity Women's Basketball Team
PE 2010 Varsity Men's & Women's Swim Team
PE 2011 Varsity Men's & Women's Indoor Track Team
PE 2012 Varsity Baseball Team
PE 2013 Varsity Softball Team
PE 2014 Varsity Men's & Women's Outdoor Track Team
PE 2015 Varsity Men's Crew Team
PE 2016 Varsity Women's Crew Team

PHYSICS

D. T. PETKIE, HEAD; D. L. MEDICH, ASSOCIATE HEAD

PROFESSORS: P. K. Aravind, G. S. Iannacchione, D. T. Petkie, L. R. Ram-Mohan, A. A. Zozulya
ASSOCIATE PROFESSORS: N. A. Burnham, D. L. Medich, R. S. Quimby, E. Tüzel, Q. Wen
ASSISTANT PROFESSORS: L.V. Titora, K. Wu
ASSOCIATE TEACHING PROFESSOR: F. A. Dick
ASSISTANT TEACHING PROFESSORS: B. Currier, S. Kadam, R. Kafle, H. Kashuri, S. Rodriguez, I. Stroe
ASSISTANT RESEARCH PROFESSOR: M. B. Popovic
ASSOCIATED FACULTY: D. Lados (ME)

MISSION STATEMENT

The Physics Department provides education in physics to both undergraduate and graduate students and contributes to the growth of human knowledge through scholarly work.

PROGRAM EDUCATIONAL OBJECTIVES

The physics department educates students with a program characterized by curricular flexibility, student project work, and active involvement of students in their learning. Through a balanced, integrated curriculum stressing the widely applicable skills and knowledge of physics, we provide an education that is strong both in fundamentals and in applied knowledge, appropriate for immediate use in a variety of fields as well as graduate study and lifelong learning.

PROGRAM OUTCOMES

We expect that physics graduates:

1. Know, understand, and use a broad range of basic physical principles.
2. Have an understanding of appropriate mathematical methods, and an ability to apply them to physics.
3. Have demonstrated oral and written communications skills.
4. Can find, read, and critically evaluate selected original scientific literature.
5. Have an ability to learn independently.
6. Understand options for careers and further education, and have the necessary educational preparation to pursue those options.
7. Have acquired the broad education envisioned by the WPI Plan.
8. Are prepared for entry level careers in a variety of fields, and are aware of the technical, professional, and ethical components.
9. Are prepared for graduate study in physics and/or other fields.

The Department of Physics at WPI offers:

i) the Bachelor of Science degree in Physics;

ii) the Bachelor of Science degree in Applied Physics;

iii) a Minor in Physics;

iv) a Minor in Astrophysics

Program Distribution Requirements for the Physics Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7) of 4 units, completion of a minimum of 10 units of study is required for physics and applied physics in the areas of mathematics, physics, and related fields as follows:

PHYSICS (PH)

REQUIREMENTS	MINIMUM UNITS
1. Mathematics (Note 1).	3
2. Physics (including the MQP) (Notes 2, 3).	5
3. Other subjects to be selected from mathematics, science, engineering, computer science, and business (Note 3).	2

NOTES:

1. Mathematics must include at least 2/3 unit of mathematics at the level of MA 3000 or higher.
2. ES 3001 and CH 3510 count as physics courses.
3. Either item 2 or 3 must include at least 1/3 unit from each of the five principal areas of physics: mechanics, experimental physics, electromagnetism, quantum mechanics, and thermal/statistical physics. This core distribution requirement is satisfied by successfully completing at least one course from each of the following five areas: Mechanics (PH 2201 or 2202); Experimental Physics (PH 2651 or 2601); Electromagnetism (PH 2301 or PH 3301); Quantum Mechanics (PH 3401 or 3402); and Thermal/Statistical Physics (ES 3001, CH3510, PH 2101, or PH 3206). Other courses or ISUs may satisfy one or more of these areas but must be approved by the department Undergraduate Curriculum Committee. For substitutions, the student must submit a petition with a substitution proposal prior to the activity and the activity outcome must be approved by a physics faculty who has taught in the particular area.

PROGRAM IN APPLIED PHYSICS

The applied physics option is available to students who wish to obtain an interdisciplinary education based in physics. It is the goal of this program to either enable students to develop their own interdisciplinary course of study or to pursue current interdisciplinary areas such as: biophysics, nuclear science and engineering, medical physics, optics, engineering physics, or chemical physics.

Program Distribution Requirements for the Applied Physics Major

REQUIREMENTS	MINIMUM UNITS
Mathematics (Note 1)	3
Physics (Note 2, Note 3)	5
Applied Focus (Note 4)	2

NOTES:

1. Courses must include a course in Calculus, Differential Equations, Vector Calculus, Boundary Value Problems, and may include applied mathematical courses in physics, chemistry, biology, or computer science.
2. Students must take at least one course from each of the following physics core areas:
   Mechanics (PH 2201, PH 2202, PH 4201, PH 511)
   Electromagnetism (PH 2301, PH 3301, PH 533)
   Quantum Mechanics (PH 3401, PH 3402, PH 514, PH 515)
   Thermodynamics and Statistical Mechanics (CH 3510, PH 2101, PH 3206, PH 522)
   Experimental Techniques or Laboratory (PH 2601, PH 2651)
3. To satisfy this requirement, a student must take and pass with a grade of C or better at least 1/3 unit from each of the core physics areas: Mechanics, Electromagnetism, Quantum Mechanics, Thermodynamics and Statistical Mechanics, and Experimental Techniques or Laboratory. An MQP (1 unit) is required. Physics 1110/1111, 1120/1121, 1130, and 1140 may be counted toward the 5 unit physics requirement. An MQP with substantial experimental activity, if approved in advance by the Physics Department Undergraduate Curriculum Committee, may substitute 1/3 units of an MQP in place of the Experimental Techniques / Laboratory course.
4. The Applied Focus requirement is satisfied by completing a minor in a department other than physics or by completing a coherent group of at least two units of courses in an applied field. The 2 unit program must be formulated prior to the student's final year of study by the student in consultation with his/her academic advisor and approved by the Physics Department Undergraduate Curriculum Committee.

GENERAL NOTE: Other courses or ISUs may satisfy one or more of these requirements upon prior approval by the Physics Undergraduate Curriculum Committee. For course substitutions, the student must submit a petition with a substitution proposal prior to the taking the course and the course instructor must provide a statement of support that the course will meet the qualifications of the substituted course.

PHYSICS AND APPLIED PHYSICS PROGRAMS ADVISING

Because the normal period of residency at WPI is 16 terms (fours terms for four years), there is a potential for 16 units total while the minimum graduation requirement is 15 units. The difference is a WPI-wide 1 unit (3 courses) of free-electives. The general WPI requirements of 4-units must include the Humanities and Arts requirement (2 units), the Interactive Qualifying Project – IQP (1 unit), the Social Sciences (2/3 unit), and Physical Education (1/3 unit). For PH and PHA students a minimum of 10 units in the program is required leaving an additional 1-unit of physics-electives. Thus, a great deal of flexibility exists to custom craft the curriculum.

For a student entering the study of physics, there is a natural progression of subjects which provide a foundation for advanced work within physics and applied physics programs. This constitutes a core sequence which embodies the following indispensable basic areas of study: classical mechanics, electromagnetism, a survey of modern physics, statistical and quantum physics, and laboratory experimental methods. Because the language of the exact sciences is mathematics, there is a parallel core sequence of mathematics courses normally taken either as preparation for or concurrently with the physics courses with which they are paired in the list presented below. In the following table ⟶ indicates that the mathematics course is strongly recommended; ⟷ indicates that concurrent study is acceptable.

MA 1021 Calculus I	⟷	PH 1110 Mechanics
MA 1022 Calculus II	⟷	PH 1120 Electricity and Magnetism
MA 1023 Calculus III	⟷	PH 1111 Mechanics
MA 1024 Calculus IV	⟷	PH 1121 Electricity and Magnetism
MA 1023 Calculus III	⟷	PH 1130 Modern Physics
MA 1024 Calculus IV	⟷	PH 1140 Oscillations and Waves
MA 2051 Differential Equations	⟷	PH 2202 Intermediate Mechanics II
MA 2071 Linear Algebra	⟶	PH 2651 Physics Laboratory
MA 2251 Vector/ Tensor Calculus	⟶	PH 2301 Electromagnetic Fields I
MA 4451 Boundary Value Problems	⟷	PH 3301 Electromagnetic Theory
	⟶	PH 3206 Statistical Physics
		PH 3401 Quantum Mechanics I

Physics and applied physics students should also reserve part of their undergraduate experience for developing perspective in a range of other science and engineering disciplines. A few of the many possibilities are illustrated by the following examples.

- Chemistry (CH 1010, 1030); Material Science (ES 2001). Choosing appropriate materials is often crucial in the development of new experimental techniques that can further our knowledge of physical phenomena. Conversely, the studies of physicists have had profound effects on the development of new materials.
- Electronics, both analog (ECE 2201 and 3204, and digital (ECE 2022). Electronics pervades the modern laboratory. It is valuable to learn electronic principles and designs as they are applied in modern "on-line" experimental data collection and data reduction systems.
- Computer science (CS 1101 or CS 1102 and CS 2301). Physics students will need to make skillful use of computers in present and future experimental data processing, theoretical analyses, and the storing, retrieving and displaying of scientific information.
- Engineering courses related to science. Some basic knowledge in areas such as heat transfer, control systems, fluid mechanics, stress analysis and similar topics will prove to be of great benefit to the physicist called upon to apply professional knowledge to practical engineering problems.

Building on this core and topical subject coverage, physics students are in a position to turn in any number of directions within the range of physics studies, depending on individual interests and career objectives. Six illustrative examples are outlined below. In each case the outline includes a list of recommended and related courses followed by a sampling of project opportunities in the respective areas. Selection of specific courses and projects should be determined by students' interests and the guidance of their academic advisors and the engineering-physics coordinator. For courses outside of the physics department, students are advised to discuss the prerequisites with the instructor.

1. Physics

Recommended Courses

PH 3402 Quantum Mechanics II
PH 511 Classical Mechanics
PH (ISU) Selected Readings in Physics

Related Courses

ECE 2029 Introduction to Digital Circuit Design
ECE 2311 Continuous-Time Signal and System Analysis
ECE 2312 Discrete-Time Signal and System Analysis
ES 3011 Control Engineering I
MA 4291 Applicable Complex Variables
PH 2510 Atomic Force Microscopy
PH 3501 Relativity
PH 3502 Solid State Physics
PH 3503 Nuclear Physics
PH 3504 Optics
PH (ISU) Modern Optics

2. Computational Physics

Recommended Courses

MA 3257 Numerical Methods for Linear and Non-Linear Systems
MA 4411 Numerical Solutions of Differential Equations
PH (ISU) Numerical Techniques in Physics

Related Courses

ECE 2029 Introduction to Digital Circuit Design
ECE 2311 Continuous-Time Signal and System Analysis
ECE 2312 Discrete-Time Signal and System Analysis
ES 3011 Control Engineering I
CS 1101 Introduction to Program Design
CS 2011 Introduction to Computer Organization and Assembly Language
CS 2301 Systems Programming for Non-Majors
CS 4731 Computer Graphics
MA 3457/CS 4033 Numerical Methods for Calculus and Differential Equations
MA 4291 Applicable Complex Variables
PH 3402 Quantum Mechanics II
PH 3502 Solid State Physics

3. Optics

Recommended Courses

PH 2501 Photonics
PH 2502 Lasers
PH 3504 Optics

Related Courses

AR/ID 3150 Light, Vision, and Understanding
ECE 2311 Continuous-Time Signal and System Analysis
ECE 2312 Discrete-Time Signal and System Analysis
ES 3011 Control Engineering I
MA 4291 Applicable Complex Variables
PH 3402 Quantum Mechanics II
PH 3502 Solid State Physics

4. Electromagnetism

Recommended Courses

PH (ISU)	Modern Optics
PH (ISU)	Selected Readings in Electromagnetism

Related Courses

ECE 2311	Continuous-Time Signal and System Analysis
ECE 2312	Discrete-Time Signal and System Analysis
ES 3011	Control Engineering I
MA 4291	Applicable Complex Variables
PH 3402	Quantum Mechanics II
PH 3502	Solid State Physics
PH 3503	Nuclear Physics
PH 3504	Optics
PH 514/5	(Graduate) Quantum Mechanics
PH 533	(Graduate) Electromagnetic Theory

5. Nuclear Science and Engineering

Recommended Courses

NSE 510	Introduction to Nuclear Science and Engineering
NSE 520	Applied Nuclear Physics
PH (ISU)	Nuclear Physics Applications
PH 3503	Nuclear Physics

Related Courses

ECE 2029	Introduction to Digital Circuit Design
ECE 3801	Advanced Logic Design
ES 3011	Control Engineering I
ME 4832	Corrosion and Corrosion Control
PH 3402	Quantum Mechanics II
PH 3501	Relativity

6. Thermal Physics

Recommended Courses

PH 2101	Principles of Thermodynamics
or ES 2001	Introduction to Thermodynamics
or CH 3510	Chemical Thermodynamics
ES 3004	Fluid Mechanics
PH 3206	Statistical Physics
PH (ISU)	Selected Readings in Thermal Physics

Related Courses

ES 3003	Heat Transfer
ES 3011	Control Engineering I
ME 3410	Compressible Flow
ME 4429	Thermodynamic Applications and Design
PH 3502	Solid State Physics
PH 3504	Optics

7. Biophysics

Recommended Courses

ES 3001	Introduction to Thermodynamics
ME/BME 4504	Biomechanics
ME/BME 4606	Biofluids
PH 3206	Statistical Physics
PH (ISU)	Review of Biophysics

Related Courses

BB 2550	Cell Biology
BME 2210	Biomechanical Signals, Instruments, and Measurements
BME 2511	Introduction to Biomechanics and Biotransport
CH 4110	Protein Structure and Function
CH 4120	Lipids and Biomembrane Functions
CH 4160	Membrane Biophysics
ES 3004	Fluid Mechanics

MINOR IN PHYSICS

The Physics Minor offers non-Physics majors the opportunity to broaden their understanding of both the principles of physics and the application of those principles to modern day engineering problems. In these times of rapid technological change, knowledge of fundamental principles is a key to adaptability in a changing workforce.

Two units of coordinated physics activity are required for the Physics Minor, as follows (note that, in accordance with Institute policy, no more than 3/3 of these units may be double-counted toward other degree requirements):

1. Any or all of the following four introductory courses:
   PH 1110 or PH 1111
   PH 1120 or PH 1121
   PH 1130
   PH 1140
2. At least 2/3 unit of upper level physics courses (2000 level or higher), which may include ISU courses or independent studies approved by the program review committee. Examples of courses of this type which might be selected are (but are not limited to):

PH 2201	Intermediate Mechanics I
PH 2301	Electromagnetic Fields
PH 2651	Physics Laboratory
PH 3401	Quantum Mechanics I
PH 3504	Optics
PH 2501	Photonics
ISU	Quantum Engineering

   Students who have taken the four course introductory sequence should have an adequate physics background for these courses; see, however, the individual course descriptions for the expected mathematical background. Other physics courses may be selected for the physics minor, but the recommended background for such courses often includes one or more of the courses listed above.
3. Capstone Experience

   The capstone experience for the physics minor can be satisfied either by an independent study project (ISU) arranged for this purpose, or by one of the upper level courses. IF the second option is chosen, the student must discuss this with the instructor prior to the start of the course. In either case, documentation of the capstone experience will consist of a paper, prepared in consultation with the instructor or independent study project advisor, which incorporates and ties together concepts learned in the physics courses selected.

For more information, or assistance in selecting a minor advisor or an independent study advisor, see the Head of the Physics Department in Olin Hall 119.

Majors in Physics or Applied Physics do not qualify for a Minor in Physics.

MINOR IN ASTROPHYSICS

For students of the sciences interested in the stars and seeking to acquire a minor expertise with a cosmic perspective, the Physics Department offers a Minor in Astrophysics. Candidates for the Minor complete two units of work, with one unit of Astrophysics courses, and one unit of recommended background courses consisting of: 1/3 unit of mechanics, 1/3 unit of electromagnetism and 1/3 unit of quantum mechanics.

Astrophysics Courses:

Astrophysics	PH 2520
Solar Systems	PH 2540
Space Environments	PH 2550/AE 2550

Recommended Background Courses (choose one from each category):

Mechanics	PH 1110/1111, PH 2201, PH 2202, PH 4201, or PH 511
Electromagnetism	PH 1120/1121, PH 2301, PH 3301, or PH 533
Quantum Mechanics	PH 1130, PH 3401, PH 3402, or PH 514

Candidates also complete an Astrophysics Minor Project either as part of one of the astrophysics courses or as a separate ISU. The project consists of: a) selecting an astrophysical topic of interest, b) posing a relevant question and performing in-depth analysis and investigation, and c) writing a paper, all in consultation with the instructor advising the project.

Students majoring in Physics or in Applied Physics may not do a Minor in Astrophysics.

Students complete the "Application for a Minor in Astrophysics" and present it to the Head of the Physics Department. The Application is available in the Physics Department Office. The Head of the Physics Department will be responsible for the review and approval of all requests for the Minor. WPI policy requires that no more than one unit of course work be double counted toward other degree requirements.

PRE-PROFESSIONAL PROGRAMS

FIVE-YEAR DUAL BACHELOR/M.S. IN MANAGEMENT (MSMG)

The combination of a technical undergraduate degree and a graduate degree in business has been cited by many experts as the ideal educational preparation for a career in private industry. For that reason, the Robert A. Foisie School of Business offers the opportunity for obtaining dual degrees - the Bachelor of Science (BS) and the Master of Science in Management (MSMG). Moreover, the MSMG provides a compelling pathway to the Master of Business Administration (MBA) while recognizing the value of work experience. Upon receiving your MSMG from WPI, and after a minimum of two years of work experience and within six years of completing your MSMG, you may apply to return to WPI, either full-time or part-time, to earn your MBA with just nine additional courses, including the hallmark project experience of WPI.

The dual BS/MS in Management program can potentially be completed within four years, however, the program is demanding, and curriculum planning with the student's advisor and the Foisie Business School should start by the beginning of the student's third year at WPI. Only registered WPI undergraduates may enter the dual-degree program. A separate and complete application to the MSMG program must be submitted. Students must be accepted into the MSMG program before they may register for graduate business courses. Admission to the dual BS/MSMG program is determined by the Foisie Business School.

A student in the dual BS/MSMG program continues to be registered as an undergraduate until the bachelor's degree is awarded. BS/MSMG students must satisfy all requirements for the bachelor's degree, including distribution and project requirements, as well as all MSMG requirements.

MSMG students must complete the following seven required courses:

- ACC 500 Accounting and Finance Fundamentals (1 credit) and ACC 502 Financial Intelligence and Strategic Decision Making (2 credits)
- BUS 500 Business Law, Ethics, and Social Responsibility
- FIN 503 Financial Decision Making for Value Creation
- MIS 500 Innovating with Information Systems
- MKT 500 Marketing Management
- OBC 505 Teaming and Organizing for Innovation
- OIE 501 Designing Operations for Competitive Advantage

Students then select three electives, at least one of which must be from the Business School.

A student in the dual BS/MSMG may, with prior approval, apply the equivalent of a maximum of 12 graduate credits from the same courses toward both the bachelor's and master's degrees.

Students enrolled in a BS/MS program may take the following graduate courses in lieu of the corresponding undergraduate course. However, once credit is received for the graduate course, students may not receive credit for the corresponding undergraduate course.

- MIS 584 Business Intelligence/ MIS 4084 Business Intelligence
- MIS 585 User Experience Design/MIS 4741 User Experience and Design
- MKT 561 Consumer Behavior/MKT 3650 Consumer Behavior
- OIE 501 Designing Operations for Competitive Advantage/BUS 3020 Achieving Effective Operations
- OIE 542 Risk Management and Decision Analysis/OIE 3510 Stochastic Models
- OIE 553 Global Purchasing and Logistics/OIE 4460 Global Planning and Logistics
- OIE 559 Optimization Methods Business Analysis/OIE 4420 Practical Optimization

PRE-HEALTH PROGRAMS

ADVISOR: E. JACOBY

Students at WPI who wish to pursue careers in the health professions (e.g. medicine, dentistry, veterinary medicine, etc.) should, in consultation with their academic advisors, plan their academic programs to include courses in biology, general and organic chemistry, biochemistry, and physics including laboratory experiences. Although required courses for certain majors will naturally overlap with professional school prerequisites more than others, entry into medical or other health professions schools may be accomplished through any major program of study. It is important for students to work closely with their faculty advisors as well as the pre-health advisor to formulate an academic plan of study that will include the courses required for admission to health professions schools while still allowing for completion of all degree requirements. Individual admissions requirements will vary by school and program. Students should consult admissions websites of individual health professions programs for specific information about prerequisites. Pre-med students are encouraged to consult the Medical School Admissions Requirement (MSAR) resource.

WPI's project-focused curriculum offers a tremendous advantage to pre-health students. Health professions programs value teamwork, as well as cross-cultural, research, and community service experience, all of which can be demonstrated through project work. Because students will graduate from WPI with a degree in an academic discipline, they will have other career opportunities should they decide not to pursue a career in a health profession or should they choose to work for some time after graduation before continuing on to a health professions school. Students and alumni applying to health professions schools should plan to meet with the pre-health advisor to discuss the application process and arrange a letter of recommendation from the pre-health committee (if required) to support their application. Such meetings should ideally begin during a student's first year as an undergraduate student (or as soon as a student decides to pursue this path) and continue through their time at WPI.

PRE-LAW PROGRAMS

ADVISOR: K. RISSMILLER

Law schools do not require that undergraduates complete any particular course of study. Thus, students who complete degrees in engineering and science may wish to consider careers in law. Undergraduates interested in attending law school are encouraged to choose from among the many courses offered which explore legal topics. For those with greater interest, WPI offers a Minor in Law and Technology described on page 121. Courses with substantial legal content are listed among those courses fulfilling the requirements of the minor.

Enrolling in these courses will introduce students to the fundamentals of legal process and legal analysis. Students will study statutes, regulations and case law. These courses will, therefore, offer the student valuable exposure to the kind of material commonly studied in law schools and they may help demonstrate a student's interest to law school admission committees. IQPs in Law and Technology, or other projects that involve library research and extensive writing may also be helpful.

A pre-law advising program in the Social Science Department maintains information on careers in law, law schools, and the law school admission test (LSAT), which is universally required. Students may examine this material independently or make an appointment. Students with an interest in law are also encouraged to join the Pre-Law Society. To do so, contact Professor Rissmiller.

TEACHER PREPARATION PROGRAM

ADVISOR: S. WEAVER

Licensed teachers in STEM fields are in continual high demand across the United States. By participating in and successfully completing this program, WPI students are able to obtain a degree in the major of their choice and receive a Massachusetts Initial Teaching License in middle or high school science, math, or technology/engineering often within 4 years. Teacher Prep students must complete the following requirements:

- PSY 2401 Psychology of Education
- PSY 2410 School Psychology
- ID 3100 Teaching Methods
- ID 3200 Sheltered English Immersion
- Successfully complete a teaching practicum in a local public middle or high school, often completed as an IQP
- Pass the state MTEL teaching test in (1) Communication and Literacy Skills and (2) relevant subject matter
- Participate in four senior year workshops

Specific content courses are required to meet State Subject Matter Knowledge requirements for each content area but these are generally covered by courses in the student's major. By joining this program, a student is able to pursue their content area of choice as well as make a difference in the lives of middle and high school students. Students wishing to discuss or pursue this opportunity should see Shari Weaver (STEM Education Center) and/or visit www.wpi.edu/+teach. Applications are available online and should be submitted no later than B term of sophomore year.

ROBOTICS ENGINEERING

DIRECTOR: J. XIAO
ASSOCIATE DIRECTOR: C. B. PUTNAM
PROFESSORS: G. Fischer (ME), M. A. Gennert (CS), W. R. Michalson (ECE), J. Xiao (RBE)
ASSOCIATE PROFESSOR: C.D. Onal (ME)
ASSISTANT PROFESSORS: B. Calli (CS), L. Fichera (CS), J. Fu (ECE), Z. Li (ME), C. Pinciroli (CS), X. Zeng (ME), H. Zhang (BME)
TEACHING PROFESSOR: K.A. Stafford (ME)
ASSISTANT RESEARCH PROFESSOR: M. B. Popovic (PH)
ASSISTANT TEACHING PROFESSORS: M. Agheli Hajiabadi (ME) G. C. Lewin (CS)
SENIOR INSTRUCTORS: N. Bertozzi (RBE), C. B. Putnam (CS)
ADJUNCT FACULTY: R. Hammoud, M.S. Ibn Seddik, C. Morato (RBE), J. Nafziger (RBE), W. L. Rasmussen (RBE), K.A. Stafford (ME)
ASSOCIATED FACULTY: E. O. Agu (CS), H. K. Ault (ME), S. Barton (HUA), T. Bergstrom (ME), C. Brown (ME), G. R. Gaudette (BME), A. H. Hoffman (ME), X. Huang (ECE), D. Korkin (CS), Y. Liu (ME), F. J. Looft (ECE), P. Radhakrishnan (ME), C. L. Sidner (CS), J. Skorinko (SSPS), E. Solovey (CS), A. Wyglinski (ECE)
RESEARCH STAFF: C. Nycz (RBE), R. Tsumura (BME), Y. Zheng (ME)
FACULTY EMERITUS: D. Cyganski (ECE), K.A. Stafford (ME)

MISSION STATEMENT

Robotics combines sensing, computation, and actuation in the real world, defined as intelligent connection from perception to action. Intelligent robotics is playing a key role in the fourth industrial revolution as it fuses technologies that connect physical, digital, biological, and social spheres. Robotics is becoming omnipresent in serving societal needs, with wide-range applications, including medicine and healthcare, transportation, manufacturing, material handling, exploration in space and deep sea, defense, domestic help, search and rescue, and emergency responses.

PROGRAM EDUCATIONAL OBJECTIVES

Graduates of the Robotics Engineering program are expected to:

1. Successfully
   a. attain professional careers in robotics and related industries, academia, and government;
   b. expand human knowledge through research and development; and/or
   c. develop entrepreneurial engineering activities.
2. Engage in life-long and continuous learning, including advanced degrees.
3. Exert leadership over multi-disciplinary projects and teams.
4. Contribute as responsible professionals through community service, mentoring, instructing, and guiding their professions in ethical directions.
5. Communicate effectively to professional and business colleagues, and the public.

STUDENT OUTCOMES

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies
8. an ability to evaluate and integrate the mechanical, electrical, and computational components of a cyber-physical system.
9. an ability to recognize and take advantage of entrepreneurial opportunities.

Program Distribution Requirements for the Robotics Engineering Major

REQUIREMENTS	MINIMUM UNITS
1. Mathematics (Note 1)	7/3
2. Basic Science (Note 2)	4/3
3. Entrepreneurship	1/3
4. Social Implications (Note 3)	1/3
5. Engineering Science and Design, including the MQP (Notes 4–9)	6 *

NOTES:

1. Must include Differential and Integral Calculus, Differential Equations, Linear Algebra, and Probability.
2. Must include at least 2/3 units in Physics.
3. Must include at least 1/3 unit of Social Implications of Technology (CS 3043, GOV 2302, GOV/ID 2314 or RBE 3100). If GOV 2302 or GOV/ID 2314 are double-counted as meeting the Social Science Requirement and the Social Implications Requirement, then the Distribution Requirements total 10 units, otherwise the Distribution Requirements total 10 1/3 units.
4. Must include at least 5/3 units in Robotics Engineering, including RBE 2001, RBE 2002, RBE 3001, and RBE 3002, or equivalent. RBE 3100 may not be used to fulfill this requirement.
5. Must include at least 1 unit in Computer Science, including Object-Oriented Programming and Software Engineering.
6. Must include at least 2/3 units in Electrical and Computer Engineering, including Embedded Systems.
7. Must include at least 1/3 unit in Statics and 1/3 unit in Controls.
8. Must include at least 1 unit of Engineering Science and Design Electives, of which at least 2/3 unit must be at the 4000-level or higher.
9. The MQP must be a Capstone Design Experience in Robotics Engineering.

MAJOR QUALIFYING PROJECTS

Robotics Engineering MQPs are capstone design activities that span a wide range of topics from autonomous ground/air/underwater vehicles to swarm robotics to human-robot interaction, with applications in surgery, inspection, manufacturing, security, and entertainment, to name but a few. All RBE MQPs must go through the breadth of the design experience, including conceptualization, requirements, design, implementation, evaluation, and documentation. Projects also address societal issues, including professional responsibility, ethical and environmental considerations, sustainability, aesthetics, and safety. RBE MQPs may be sponsored by industry, including the Lincoln Lab and Silicon Valley project centers, develop from faculty research, or be initiated by students. Please see the Robotics Engineering website http://robotics.wpi.edu/ for information on current projects.

ADDITIONAL ADVICE

For additional advice about course selections, including elective choices, students should consult with their academic advisor.

MINOR IN ROBOTICS ENGINEERING

The Minor in Robotics Engineering consists of 2 units of work distributed as follows:

1. 1/3 unit CS selected from CS 2102, CS 2103, CS 2223, CS 2301, CS 2303, CS 3733.
2. 1/3 unit ECE selected from ECE 2010, ECE 2019, ECE 2029, ECE 2049, ECE 2311.
3. 1/3 unit ME/ES selected from ES 2501, ES 2503, ES 3011, ME 3310.
4. 2/3 units from RBE 1001, RBE 2001, RBE 2002.
5. A 1/3 unit capstone experience through an RBE course at 3000-level or above.

No more than 1 unit of work may overlap the major.

Students considering a Robotics Engineering Minor should consult with the RBE Undergraduate Program Committee.

SOCIAL SCIENCE AND POLICY STUDIES

E. M. DOUGLAS, HEAD

FACULTY: I. Arroyo, E. M. Douglas, J. K. Doyle, L. Elgert, R. Krueger, E. Ottmar, O. Pavlov, M. J. Radzicki, K. J. Rissmiller, A. C. Rodriguez, K. Saeed, J. Skorinko, A. Smith, G. Somasse, P. Stapleton, E. Stoddard

FACULTY EMERITUS: J. O'Connor, D. Woods

ASSOCIATED FACULTY: S. Barton (HU), J. Beck (CS), N. Heffernan (CS), K. Oates (BB), D. Rosbach (CEE)

DEPARTMENT DESCRIPTION

Recognizing the increasingly important role that the social sciences play in our complex, technological world, the Department of Social Science and Policy Studies offers cutting edge educational and research programs in a variety of disciplines, including economics, environmental and sustainability studies, development studies, government/law, learning sciences, psychology, sociology, and system dynamics. Our programs, ranging from undergraduate general education in the social sciences to interdisciplinary Ph. D. degrees, are distinguished by their emphasis on behavioral science, commitment to project-based learning, and use of state of the art methods and technologies. We are committed to helping students at all levels to think critically about important societal problems and to identify effective solutions.

PROGRAMS

The SSPS Department supports general education in the social sciences through the university-wide Social Science Requirement. The Department offers B.S. degrees and minors in Economic Science, Psychological Science, Society, Technology & Policy, and System Dynamics. The Department also serves as the home for the Pre-Law program and Law & Technology Minor and is the lead department for the interdisciplinary BA and minor program in International Development, Environment, and Sustainability. Given the diversity of offerings in the department, each program has a unique set of goals and outcomes.

For additional advice about course selections, students should consult with their academic advisor. Detailed curriculum guidelines for each program as well as recommendations for completing the Social Science Requirement are available on the Social Science and Policy Studies Department Web site (www.wpi.edu/academics/ssps.html).

COURSE AREAS

The SSPS Department covers many of the traditional social science disciplines. Courses with the following prefixes are found in the Department:

DEV	Development
ECON	Economics
ENV	Environmental and Sustainability Studies
GOV	Political Science, Government, and Law
PSY	Psychology
SD	System Dynamics
SOC	Sociology
SS	General Social Science
STS	Society-Technology Studies

DOUBLE MAJOR IN SOCIAL SCIENCE AND POLICY STUDIES

Any of the major programs offered by the SSPS Department may be taken as part of a double major in which the student majors in an area of science, engineering or business as well as social science. To obtain a double major, the student must satisfy all of the degree requirements of both majors, including the MQP and Distribution requirements. However, the MQP in the social science discipline may double count as the IQP, provided that the combined project meets the goals of both. It must be interactive in nature involving an aspect of technology as well as an application of social science knowledge and analytical techniques. Thus double majors for whom one of the majors is in the social sciences requires only two projects, not three. The decision to pursue the social science double major should be made fairly early in the student's academic career, certainly early enough to ensure the selection of an appropriate IQP/MQP.

UNDERGRADUATE RESEARCH OPPORTUNITIES

SSPS faculty are actively engaged in research in a variety of applied social science areas, with particular strength in economics, environmental studies, learning sciences, psychology, social and public policy, and system dynamics.

ECONOMIC SCIENCE PROGRAM

A. Smith: Program Director

Economists study how both individuals and institutions make decisions about the utilization and distribution of resources. They also monitor economic data and analyze trends, examine the impact of economic policies and behaviors, and help formulate new policies and anticipate their effects. WPI's economic science major emphasizes the use of computational modeling and experimentation to achieve these goals.

PROGRAM OUTCOMES

In addition to fulfilling WPI's university-wide undergraduate learning outcomes, economic science majors will demonstrate:

1. Command of macro-economic and micro-economic theory.
2. Awareness of economic history and the evolution of thought in economics.
3. Skills in key economic modeling techniques, including econometrics and system dynamics.
4. Skills using data collected in a variety of ways, including surveys, experiments and through observation in the field.
5. Skill in mathematics as required to approach and solve economic problems.
6. Practical understanding of modern business disciplines including accounting and finance.
7. Knowledge of key economic institutions that make policy and influence economic practice.
8. Ability to understand current economic issues in light of economic theories.
9. Ability to approach and solve a practical problem like an economist.
10. Deep understanding of fundamental economic problems in a specific area of application.

Program Distribution Requirements for the Economic Science Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in economics, social science, basic science, and mathematics as follows:

ECONOMIC SCIENCE REQUIREMENTS	MINIMUM UNITS
1. Economics (Note 1).	3
2. Economics and/or Business (Note 2)	2/3
3. Other Social Science	1
4. Modeling Techniques	2/3
5. Mathematics (Note 3)	2
6. Basic Science	1
7. Electives	2/3
8. MQP	1

NOTES:

1. Must include courses in both micro and macro economic theory at the intermediate level and in econometrics and international trade (available through the Consortium or independent study).
2. Must include financial accounting, BUS 2060. May include other relevant business courses as approved by the Departmental Program Review Committee.
3. Must include differential equations, integral calculus, and statistics.

CONCENTRATION AREAS AVAILABLE IN ECONOMIC SCIENCE

Economic Science majors may focus their studies by choosing a Concentration within one of the following two specific areas of Economics: Sustainable Economic Development and Computational Economics. These concentration areas reflect the growing importance of environmental issues and computational tools within the discipline of economics and are areas of strength in teaching and research in the social sciences at WPI. Concentrations within the Economics Science major comply with WPI's requirements for concentrations. Students must complete an MQP and two units of integrated study in the area of their Concentration.

Sustainable Economic Development. The term sustainable economic development means choosing policies that balance environmental preservation and economic development so as to meet the needs of the present generation without seriously compromising the needs of future generations. The sustainable development concentration examines the economic, psychological, social, political, legal, and technical issues surrounding the creation of policies aimed at establishing sustainable economic systems at the local, national, and international levels.

1. 1 unit from the following list of courses in economic development:

ECON 2125	Development Economics
ECON 2117	Environmental Economics
CE 3070	Urban Environmental Planning
CE 3074	Environmental Analysis
HI 3333	Topics in American Technological Development

2. 1 unit from the following list of environmental courses in other social science disciplines, humanities, and biology, or additional courses from list 1:

BB 1002	Environmental Biology
BB 4150	Environmental Change: Problems and Approaches
ENV 1100	Introduction to Environmental Studies
ENV2200	Environmental Studies in the Various Disciplines
ENV 2400	Environmental Problems and Human Behavior
GOV 2311	Legal Regulation of the Environment
GOV 2312	International Environmental Policy
PY 2717	Philosophy and the Environment

Computational Economics. Students in the computational economics concentration supplement their knowledge of traditional tools of economic analysis by studying modern computational techniques. Student projects may address problems of complex macroeconomic modeling, chaos, computational finance, design of automated Internet markets, and many more. This concentration draws on the expertise and talent of the faculty in various departments throughout the university.

1. 1 unit from the following list of courses in system dynamics:

SD 1510	Introduction to System Dynamics Modeling
SD 2530	Advanced Topics in System Dynamics Modeling
SD 3550	System Dynamics Seminar

2. 1 unit from the following list of courses offered in other departments:

CS 2022/MA2201	Discrete Mathematics
CS 4032/MA3257	Numerical Methods for Linear and Nonlinear Systems
CS 4033/MA3457	Numerical Methods for Calculus and Differential Equations
CS 4341	Introduction to Artificial Intelligence
ES 3011	Control Engineering I
OIE 3460	Simulation Modeling and Analysis
OIE 3510	Stochastic Models
MA 2210	Mathematical Methods in Decision Making
MA 2431	Mathematical Modeling with Ordinary Differential Equations
MA 3471	Advanced Ordinary Differential Equations
MA 4235	Mathematical Optimization
MA 4411	Numerical Analysis of Differential Equations

PSYCHOLOGICAL SCIENCE PROGRAM

J. Skorinko: Program Director

Psychology is the study of the entire range of human experience, thought, and behavior, from infancy until death, from the most abnormal behavior to the most mundane, from the behavior of neurons to the actions of societies and nations. Psychologists employ a wide variety of methods to understand behavior and to discover how best to improve performance, including controlled experiments on human subjects. WPI's major in psychological science emphasizes empirical research in the areas of social and cognitive psychology as well as practical applications to the classroom, the courtroom, and other settings.

PROGRAM OUTCOMES

In addition to fulfilling WPI's university-wide undergraduate learning outcomes, psychological science majors will demonstrate:

1. Familiarity with the major concepts, theoretical perspectives, empirical findings, and trends in psychology.
2. Understanding of and ability to apply basic research methods in psychology, including experimental design, data analysis, and interpretation.
3. Ability to apply psychological principles to personal, social, organizational, and societal issues, including developing insight into their own and others' behavioral and mental processes.
4. Understanding of the relationship and interactions between psychology and other social science domains.
5. Ability to understand the role of and apply knowledge of psychological phenomena in other domains, such as business, computer science, or biology.
6. Ability to recognize, understand, and respect the complexity of sociocultural and international diversity.
7. Understanding of the ethics of human subjects research and the ability to apply that understanding in designing research or practices that do not violate ethical guidelines.
8. Knowledge of basic science and how it contributes to understanding human behavior.

[Adapted from the American Psychological Association Report on Undergraduate Psychology Learning Goals and Outcomes.]

Program Distribution Requirements for the Psychological Science Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in psychological science, social science, basic science, and mathematics as follows:

PSYCHOLOGICAL SCIENCE REQUIREMENTS	MINIMUM UNITS
1. Psychological Science (Note 1)	4
2. Psychological Science and/or Related Courses (Note 2)	4/3
3. Basic Science, Computer Science, and/or Engineering (Note 3)	5/3
4. Mathematics (Note 4)	1
5. Electives (Note 5)	1
6. MQP	1

NOTES:

1. Must include introductory psychology, social psychology, cognitive psychology, and experimental design.
2. Related courses may be additional psychology courses, other social science courses (DEV, ECON, ENV, GOV, SD, SOC, STS), ID 2050, or they may be chosen from a list of psychology-related courses from other departments listed in the undergraduate catalog section for the Psychological Science major.
3. Must include 1/3 unit of biology. Must include 1/3 unit of computer science (except CS 2022 and CS 3043).
4. Must include 2/3 units of calculus and 1/3 unit of statistics.
5. The 1 unit of electives must be approved by the Director of the Psychological Science Undergraduate Program.

List of psychology-related courses from other departments:

BB 2050	Animal Behavior
BB 2920	Genetics
BB 3080	Neurobiology
BB 3101	Human Anatomy & Physiology: Movement and Communication
BB 3102	Human Anatomy & Physiology: Transport and Maintenance
BB 3620	Developmental Biology
BME 2211	Biomedical Data Analysis
BME 3111	Physiology and Engineering
BME 3300	Biomedical Engineering Design
BUS 1010	Leadership Practice1
BUS 2080	Data Analysis for Decision Making
BUS 4030	Achieving Strategic Effectiveness
CS 3041	Human-Computer Interaction
CS 3043	Social Implications of Information Processing
CS 4341	Introduction to Artificial Intelligence
CS 4445	Data Mining and Knowledge Discovery in Databases
EN 1257	Introduction to African American Literature and Culture
EN 2225	The Literature of Sin
EN 2251	Moral Issues in the Modern Novel
HU 1412	Introduction to Asia
HU 2340	Popular Culture and Social Change in Asia
INTL 1100	Introduction to International and Global Studies
INTL 2410	Modern Africa
PY 2711	Philosophical Theories of Knowledge and Reality
PY 2716	Philosophies of Difference
PY 2718	Freedom and Existence
RE 2721	Religion and Culture
RE 2722	Modern Problems of Belief
ID 2050	Social Science Research for the IQP
IMGD 2000	Social Issues in Interactive Media and Games
MA 2612	Applied Statistics II
MA 2621	Probability for Applications or MA2631: Probability
MA 3631	Mathematical Statistics
DS 3001	Foundations of Data Science

CONCENTRATION IN PSYCHOBIOLOGY

CONCENTRATION GUIDELINES:

1. Psychological Science Majors who are interested in the biological aspects of psychology can choose to complete a concentration in Psychobiology. To complete the concentration, students must complete 2 units of coursework from the approved list of courses related to psychobiology.
2. All students completing this concentration will need to complete an MQP that relates to psychobiology.
3. 2/3 units should come from the Psychological Science and may include (see Note 1):

PSY 1404:	Developmental Psychology
PSY 1412:	Mental Health
PSY 2408:	Health Psychology
PSY 2502:	Psychophysiology

4. 4/3 units should come from Biology & Biotechnology and may include (see Note 1):

BB 1025:	Human Biology
BB 1035:	Intro to Biotechnology
BB 2003:	Fundamentals of Microbiology
BB 2050:	Animal Behavior
BB 2550:	Cell Biology
BB 2903:	Anatomy & Physiology (1/6)
BB 2904:	Ecology, Environment, and Animal Behavior (1/6)
BB 2920:	Genetics
BB 2950:	Molecular Biology
BB 3080:	Neurobiology
BB 3101:	Human Anatomy & Physiology: Movement and Communication
BB 3102:	Human Anatomy & Physiology: Transport and Maintenance
BB 2511:	Nerve and Muscle Physiology
BB 3514:	Circulatory and Respiratory Physiology
BB 3620:	Developmental Biology

NOTES:

1. Only one course in this subset can be at the 1000-level

SOCIETY, TECHNOLOGY, AND POLICY PROGRAM

P. Stapleton: Program Director

Policy analysts apply an array of skills and techniques to evaluate the impacts of existing policies, both public and private, and to help formulate new policies to address societal needs. WPI's major in society, technology, and policy focuses on the relationships between science-technology, society, government, and business. The program allows students to develop a strong interdisciplinary background in these areas and to learn the analytical tools and methods needed to apply this knowledge to important questions in such areas as environmental policy and regulation, science-technology policy, and internet policy.

PROGRAM OUTCOMES

In addition to fulfilling WPI's university-wide undergraduate learning outcomes, society, technology, and policy majors will demonstrate:

1. Ability to conduct public policy analysis, technology assessment, or social impact analysis.
2. Understanding of and ability to apply research methods in the social sciences.
3. Ability to communicate effectively the results of a social analysis with policy implications in speech and writing.
4. Understanding of the relationships between technology, policy, and the public interest in a democratic society.
5. Ability to integrate understanding of science and technology into thinking on the social implications of science and technology.
6. Ability to understand the impacts of government regulation on the future development of a technology or industry.
7. Literacy in the technological aspects of policy issues in the student's area of concentration.
8. Ability to identify and appropriately consider ethical constraints during science and technology policy deliberations and decision-making.

Program Distribution Requirements for the Society, Technology, and Policy Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in social science, basic science, and mathematics as follows:

SOCIETY, TECHNOLOGY AND POLICY REQUIREMENTS	MINIMUM UNITS
1. Social Science (Notes 1, 2)	4
2. Minimum Basic Science background	2/3
3. Minimum Mathematics background (Note 3)	1
4. Technical concentration (Note 4)	5/3
5. Electives (Note 5)	5/3
6. MQP	1

NOTES:

1. Students must obtain approval of their proposed program from the Departmental Program Review Committee. Course distribution will focus on a disciplinary specialty and either policy analysis or a society-technology specialization such as Social Impact Analysis or Technology Assessment.
2. Relevant Humanities or Business courses approved by the Departmental Review Committee may be counted for a maximum of 2/3 of a unit in fulfilling the 4-unit requirement.
3. One course in calculus-based statistics is required.
4. A series of courses in one field of science, engineering, or business or a combination of courses approved by the departmental review committee which focus on issues to be developed in the MQP.
5. These courses are to be approved by the Departmental Review Committee and are meant to broaden the technical concentration and tie it to social concerns.

MINOR IN LAW AND TECHNOLOGY

As science and technology evolve, there are growing needs for professionals who both understand science and technology and who work within the institutions of the American legal system. At all levels, from federal courts to state regulatory agencies and local planning commissions, policy makers decide issues in an environment of legal rules and principles. Yet to be effective, they must also understand how science and technology can aid their decisions, the methods and conclusions of scientific research, and the social impact of decisions. Without science, environmental regulators cannot decide on measures for hazardous waste disposal, public health officials cannot evaluate new drug therapies, utility regulators cannot authorize new sources of electric power, judges cannot construe the meaning of medical testimony, and attorneys cannot cross examine an expert witness in a product failure case. Decision makers, and those who attempt to influence them, find that they need to understand science and technology.

The Law and Technology Program is an interdisciplinary minor that can be used to supplement a major, introduce students in science and engineering disciplines to legal studies and prepare students to enter law school upon graduation. Students in the program begin their studies with a foundation in legal institutions and analysis and continue with advanced courses that integrate law and technology. A course in professional communication is also required.

To attain a Minor in Law and Technology, students must complete two units of study (6 courses) as follows:

1. At least two of the following courses in legal fundamentals:
   HI 2317 Law and Society in America, 1865-1910
   GOV 1310 Law, Courts and Politics
   GOV 2310 Constitutional Law: Foundations
   GOV 2320 Constitutional Law: Civil Rights and Liberties
   BUS 2020 The Legal Environment of Business Decisions
2. At least two of the following courses which integrate law and technology:
   CE 3022 Legal Aspects of Professional Practice
   CE 4071 Land Use Development and Controls
   CE 583 Contracts and Law for Civil Engineers
   GOV 2302 Science-Technology Policy
   GOV 2311 Environmental Policy and Law
   GOV 2312 International Environmental Policy
   GOV 2313 Intellectual Property Law
   GOV/ID 2314 Cyberlaw and Policy
   Independent study or experimental courses with the approval of the program director.
   One-third unit of IQP may also be credited toward the minor with the approval of the program director.
3. One of the following courses in professional communication:
   WR 1010 Elements of Writing
   WR 2210 Business Writing and Communication
   WR 3112 Rhetorical Theory
   WR 3214 Writing About Disease and Public Health

Students should review their program of study with the associated faculty and/or pre-law advisor. Students are also encouraged to seek IQP opportunities in Division 53, Law and Technology. Note: only one of the two units may be counted toward other college requirements.

For general policy on the Minor, see description on page 11.

MINORS IN SOCIAL SCIENCE

A Social Science Minor is available in any of the following disciplines:

Economics
Sociology
Political Science and Law
Psychology
System Dynamics
Social Science

A minor in the Social Sciences consists of 2 units of academic activity satisfying the following conditions:

1. Foundations
   Introductory level courses in any one or two social science disciplines taught at WPI: economics (ECON), sociology (SOC), political science (and law) (GOV), psychology (PSY), and system dynamics (SD). Introductory courses are identified by the first digit of the course number, which must be a 1. The second digit of the course number indicates the discipline (1–economics, 2–sociology, 3–political science and law, 4–psychology, and 5–system dynamics).

2. Applied Courses (At least 1 unit)
   Three or more higher level courses in the same social science discipline as the foundation courses, which involve applications or extensions of the material covered in the introductory courses and list the introductory courses as recommended background. High level courses have either a 2, 3, or 4 as the first digit of the course number. The capstone experience will consist of a paper in the last applied course taken. The paper must draw upon and integrate material covered in the previous courses. An IQP may provide the capstone experience and substitute for the last applied course provided that the IQP was advised or co-advised by a member of the Social Science & Policy Studies department, and contains appropriate social science analysis.
3. If five or more of the six 1/3 units required for the minor are in a single social science discipline, the title of the minor will be "Minor" in that discipline.* Otherwise the title of the minor will be "Minor in Social Science." Examples of minor programs in economics, sociology, political science (and law), psychology, system dynamics and interdisciplinary social science are available at the SS & PS department office. The course selected for an interdisciplinary social science minor should follow an identifiable theme, such as the relationship between technology and society or social, political, economic or environmental policies.

Students taking minors in the social sciences are expected to designate a member of the SS & PS department as their SS minor advisor, who will assist them in preparing a program that meets the requirements of the minor. Students can obtain assistance at the SS & PS departmental office in designating an advisor.

Students completing any major in the Social Science and Policy Studies Department may not also complete a minor in social sciences.

* In designating sociology the minor, the course PSY 1402, Social Psychology, can be counted as one of the fivecourses required in Sociology. In designating the economics minor, at least 3 of the 5 required courses must be chosen from among the following four theory courses:
ECON 1110 Introductory Microeconomics;
ECON 1120 Introductory Macroeconomics;
ECON 2210 Intermediate Microeconomics; and
ECON 2120 Intermediate Macroeconomics.

COURSE DESCRIPTIONS

Courses Qualifying for Engineering Distribution Areas . . . 124
Aerospace Engineering . . . 125
Air Force Aerospace Studies . . . 126
Architectural Engineering . . . 128
Basic Sciences . . . 129
Bioinformatics and Computational Biology . . . 129
Biology and Biotechnology . . . 130
Biomedical Engineering . . . 135
Business, Robert A. Foisie School of . . . 138
Chemical Engineering . . . 142
Chemistry and Biochemistry . . . 144
Civil and Environmental Engineering . . . 148
Computer Science . . . 150
Data Science . . . 154
Electrical and Computer Engineering . . . 155
Engineering Science Interdisciplinary . . . 158
Fire Protection Engineering . . . 160
Humanities and Arts . . . 161
Independent Study . . . 179
Interactive Media & Game Development . . . 179
Interdisciplinary . . . 182
Mathematical Sciences . . . 184
Mechanical Engineering . . . 189
Military Science . . . 192
Physical Education . . . 194
Physics . . . 195
Robotics Engineering . . . 197
Social Science and Policy Studies . . . 198

SECTION 3

COURSES QUALIFYING FOR ENGINEERING DISTRIBUTION AREAS

Mathematics
All Courses designated "MA."

Advanced placement established by AP exam or through passing WPI advanced courses (see page 243) also qualify.

Basic Science
All courses designated "PH," "CH," "BB," and GE 2341.

Engineering Science/Design
The following courses may be applied to the "Engineering Science and Design" distribution requirement for each respective engineering major:

AE: All courses designated "AE"

BME: All courses designated "BME" (except BME 1001, BME 1004 and BME 3110) and CE, CHE, ECE, RBE, and ME courses at the 2000-level or above (except RBE 3100).

CE: All courses designated "CE". Also ES 2503 and ES 3004.

CHE: All courses designated "CHE." Also ES 3002, ES 3003, ES 3004, and other courses approved by the Chemical Engineering Department. See the department web site, and consult with your academic advisor for details.

ECE: All courses designated "ECE" and ES 3011 may be included in the six-unit ECE area distribution requirement.

IE: OIE courses including BUS 2080, BUS 3020, OIE 2850, OIE 3405, OIE 3410, OIE 3420, OIE 3460, OIE 3510, OIE 3600, OIE 4410, OIE 4420 and OIE 4460.

ME: All courses designated "ME".

RBE: All courses designated (except RBE 3100).

In addition, engineering majors selecting "Engineering Science/Design" courses from outside their major may choose appropriate activities from any of the following:

All courses designated ES, ECE, CHE, ME.

All OIE courses listed above (for ME majors only).

All courses designated as RBE except RBE 3100.

All courses designated as CE except CE 3022.

All courses designated as CS except CS 1101, CS 1102, and CS 3043. (Only RBE majors may select CS 1101 or CS 1102 to satisfy the Engineering Science and Design Distribution Requirement.)

(Electrical and Computer Engineering majors are restricted to these courses at the 2000-level or higher.)

All ABET engineering programs require six units of Engineering Science and Design.

All graduate-level courses may be counted in the appropriate categories.

COURSE DESCRIPTIONS

COURSE CATEGORIES

for purposes of planning programs of study, courses at WPI are divided into three categories.

Category I (Cat. I)
These courses cover core material of interest to large numbers of students. Category I courses are offered at least once a year.

Category II (Cat. II)
Category II courses are offered at least every other year

Category III (Cat. III)
Category III courses are offered at the discretion of the department/program.

BACKGROUND

Recommended
The course will build on material in the recommended course. Instructors can assume that the student is knowledgeable of the material from the recommended course or from other experiences.

Suggested
The material from this course would be helpful to the student, but it is not assumed background.

WRITING-INTENSIVE (WI) COURSE SECTIONS

Some sections of WPI courses may be labeled as "WI" in the course schedules. These sections will:

– Assign writing to teach course content and disciplinary forms of communication and reasoning;
– Provide explicit instruction in and feedback on students' written work; and
– Specify and require standards for ethical writing practices.

CATALOG AND SCHEDULE

The catalog and course schedule can be found online at https://www.wpi.edu/academics/calendar-catalogs and www.wpi.edu/+schedules.

COURSE NUMBERING

Each course at WPI is designated by a prefix identifying the subject area followed by a four digit number. The first digit is coded as follows:

1 — Courses for which first-year students will receive priority in registration. Upper class students may register on a space-available basis.
2 — Basic level courses.
3 — Advanced level undergraduate courses for which no graduate credit is given. (This restriction may be waived at the discretion of the degree department.)
4 — Advanced level undergraduate courses for which graduate credit may also be given.
5 — Graduate courses.

The last three digits may be used by the departments to indicate subject areas. Many graduate courses are also available to undergraduates.

COURSE CREDIT

Unless otherwise indicated, WPI courses usually carry credit of 1/3 unit. This level of activity suggests at least 15-17 hours of work per week, including work outside the classroom, as well as scheduled class and laboratory time. The usual workload per term is 1 unit.

AEROSPACE ENGINEERING

AE/PH 2550. ATMOSPHERIC AND SPACE ENVIRONMENTS.
Cat. I
This course introduces the ambient atmospheric and space environments encountered by aerospace vehicles. Topics include: the sun and solar activity; the solar wind; planetary magnetospheres; planetary atmospheres; radiation environments; galactic cosmic rays; meteoroids; and space debris.
Recommended background: mechanics (PH 1110/1111 or equivalent), electromagnetism (PH 1120/1121 or equivalent), and ordinary differential equations (MA 2051 or equivalent).

AE 2712. INTRODUCTION TO AEROSPACE STRUCTURES.
Cat. I
This course provides a concise overview of statics and then focuses on basic stress analysis applied to simple aerospace structures. Topics in stress analysis include: concepts of stress and strain; basic constitutive relations; one-dimensional response to axial loading; thermal stresses; statically determinate and indeterminate problems; shear forces, bending moments, bending stresses and deflections in beams with symmetric cross sections; two-dimensional stress transformation and Mohr's circle; and an introduction to energy methods in structural analysis.
Recommended background: differential, integral, multivariable calculus (MA 1021, MA 1022, MA 1024 or equivalent), mechanics (PH 1110, PH 1111, or equivalent).

AE 2713. ASTRONAUTICS.
Cat. I
An introductory course that covers the fundamentals of space flight. Topics studied include: two-body orbital dynamics, classification of orbits, and time of flight analysis; geocentric orbits and impulsive maneuvers: orbit shaping, escape trajectories, Hohmann and non-Hohmann transfers; orbital elements in 3D; interplanetary Hohmann and generalized transfers, intercepts, flybys.
Recommended background: multivariable calculus (MA 1024 or equivalent), differential equations (MA 2051 or equivalent), dynamics (ES 2503, PH 2201 or equivalent).

AE 3410. COMPRESSIBLE FLUID DYNAMICS.
Cat. I
In this course, students are introduced to various compressibility phenomena such as compression (shock) and expansion waves. Conservation laws and thermodynamic principles are applied to the description of flows in which compressibility effects are significant. One-dimensional models are applied to analysis of flow in variable area ducts, normal and oblique shock waves, expansion waves, and flows with friction and heat addition. Numerous applications from engineering are investigated including supersonic inlets, rocket nozzles, supersonic wind tunnels, gas delivery systems, and afterburning jet engines.
Recommended background: thermodynamics (ES 3001, CH 3510 or equivalent), incompressible fluid dynamics (AE 3602 or equivalent).

AE 3602. INCOMPRESSIBLE FLUIDS.
Cat. I
This course covers the fundamentals of inviscid and viscous incompressible fluid dynamics. Topics presented will be considered from the following: fluid kinematics and deformation; integral conservation laws of mass, momentum and energy for finite systems and control volumes; differential conservation laws of mass, momentum and energy; the Navier-Stokes equations; the streamfunction and the velocity potential. Applications will be considered from the following topics: hydrostatics; incompressible, inviscid, irrotational (potential) flows; incompressible boundary layer flows; viscous incompressible steady internal and external flows; and dimensional analysis.
Recommended background: differential equations (MA2051 or equivalent), dynamics (ES 2503, PH 2101 or equivalent), thermodynamics (ES 3001, PH 2101, CH 3510 or equivalent).

AE 3711. AERODYNAMICS.
Cat. I
This course introduces students to the aerodynamics of airfoils, wings, and aircraft in the subsonic and supersonic regimes. Topics covered include: prediction of aerodynamic forces (lift, drag) and moments, dynamic similarity, experimental techniques in aerodynamics, Kutta-Joukowski theorem, circulation, thin airfoil theory, panel methods, finite wing theory, subsonic compressible flow over airfoils, linearized supersonic flow, and viscous flow over airfoils.
Recommended background: incompressible and compressible fluid dynamics (AE 3602, AE 3410 or equivalent).

AE 3712. AEROSPACE STRUCTURES.
Cat. I
This course focuses on intermediate-level topics in stress analysis relevant to aerospace structures. Topics include: buckling under centric and eccentric loadings with and without lateral loads applied; torsion of solid circular and noncircular cross sections; torsion of thin-walled multi-celled members; flexural shear flow in and shear center of thin walled multi-celled members; bending stresses in beams with unsymmetric cross sections; stresses under combined loadings; and three-dimensional states of stress. The laboratory component of this course provides testing and measurement experience related to buckling of columns under a variety of loadings and support conditions; and to the determination of the shear center and bending response of beams with unsymmetric cross sections.
Recommended background: differential equations (MA 2051 or equivalent), introductory aerospace structures (AE 2712 or equivalent.)

AE 3713. INTRODUCTION TO AEROSPACE CONTROL SYSTEMS.
Cat. I
This course introduces feedback control systems analysis and design for applications to aircraft and spacecraft. Topics include: linear dynamical systems modeling of aircraft and spacecraft motion, including linearization; identification and transient response analysis of typical modes of motion; time- and frequency domain analysis; Bode plots; criteria for stability; design of stability augmentation and, attitude and orbital control systems using linear state feedback or PID control; numerical simulation of controlled and uncontrolled aircraft and spacecraft motion.
Recommended background: ordinary differential equations (MA 2051 or equivalent), introductory dynamics (ES 2503, PH 2201 or equivalent), and linear algebra (MA 2071 or equivalent).
Students may not receive credit for both AE/ME 3703 and AE 3713.

AE 4711. FUNDAMENTALS OF AIR-BREATHING PROPULSION.
Cat. I
This course introduces the principles of operation of air-breathing engines, including gas-turbines (turbojets, turbofans, and turboprops), ramjets, and scramjets. Topics covered include: engine thrust and efficiency analysis; working principles and performance analysis of diffusers, compressors, combustors, and nozzles; parametric cycle analysis; effect of irreversibilities on performance. The topics covered are also relevant to the operation of gas-turbines used for power generation.
Recommended background: thermodynamics (ES 3001, CH 3510, PH 2101 or equivalent), compressible fluid dynamics (AE 3410 or equivalent).
Students may not receive credit for both AE 4710 and AE 4711.

AE 4712. STRUCTURAL DYNAMICS.
Cat. I
This course introduces the analysis of vibrations of flexible bodies encountered as elements of aircraft and space structures. Topics include: modeling of aerospace structures with lumped parameters using Newton's Law and Lagrange's equations, free- and forced- vibration response of single degree of freedom systems and multi-degree of freedom systems, design of simplified vibration absorption systems, dynamic testing, modal analysis for determining structural response of lumped and continuous systems.
Recommended background: dynamics (ES 2503, PH 2201, PH2202 or equivalent), control (AE 3713 or equivalent), aerospace structures (AE 3712 or equivalent).

AE 4713. SPACECRAFT DYNAMICS AND CONTROL.
Cat. I
The course covers broad topics in spacecraft attitude dynamics, stability and control. The course includes a review of particle and two-body dynamics and introduction to rigid body dynamics. Orbital and attitude maneuvers are presented. Attitude control devices and momentum exchange techniques such as spinners, dual spinners, gravity gradient, and geomagnetic torques are presented. Attitude sensors/actuators are presented and the attitude control problem is introduced. Open-loop stability analysis for a variety of equilibrium conditions is discussed. Control using momentum exchange and mass expulsion (thrusters) devices is discussed. The analyses and designs will be implemented using scientific computing software such as MATLAB®.
Recommended background: astronautics (AE 2713 or equivalent), dynamics (ES 2503, PH 2201 or equivalent), control (AE 3713 or equivalent).

AE 4717. FUNDAMENTALS OF COMPOSITE MATERIALS.
Cat. I
This course provides an overview of the processing techniques and mechanical behavior of composite materials relevant to aerospace applications. Topics in this course may include: classification of composites; elasticity of composite materials; the effect of reinforcements on strength and toughness; bonding mechanisms of interfaces in composite; fabrication methods for polymer-matrix composite materials; viscoelasticity and creep of composites; advanced composites materials (bio-composites, nano-composites).
Recommended background: introductory material science (ES 2001), and introductory stress analysis (AE 2712 or equivalent).

AE 4719. ROCKET PROPULSION.
Cat. I
This course provides a study of rocket propulsion systems for launch vehicles and spacecraft. Dynamics, performance, and optimization of rocket-propelled vehicles are presented. Performance and component analysis of chemical propulsion systems are covered including flight dynamics, vehicle staging, nozzle design, and thermochemistry of bipropellant and monopropellant thrusters. Different classes of electric thrusters are introduced along with the concept of optimal specific impulse.
Recommended background: compressible fluid dynamics (AE 3410 or equivalent), thermodynamics (ES 3001, PH 2101, CH 3510 or equivalent).

AE 4723. AIRCRAFT DYNAMICS AND CONTROL.
Cat. I
This course covers models of fixed-wing aircraft dynamics, and the design of aircraft control systems. Topics include: aircraft performance, longitudinal and lateral flight dynamics, simulation methodologies, natural modes of motion, static and dynamic stability, and aircraft control systems (such as autopilot design, flight path control, and automatic landing).
Recommended background: controls (AE 3713 or equivalent), attitude and position kinematics (AE 4733 or equivalent).

AE 4733. GUIDANCE, NAVIGATION AND COMMUNICATION.
Cat. I
This course covers methods and current enabling technologies in the analysis, synthesis, and practice of aerospace guidance, navigation, and communications systems. Topics covered include: attitude- and position kinematics, inertial navigation systems, global satellite navigation systems, communication architectures for satellite navigation, tropospheric and ionospheric effects on radio-wave propagation, least squares estimation, the Kalman filter, and pursuit guidance.
Recommended background: linear algebra (MA 2071 or equivalent), dynamics (ES 2503, PH 2201 or equivalent), and controls (AE 3713 or equivalent).

AE 4770. AIRCRAFT DESIGN.
Cat. I
This course introduces students to design of aircraft systems. Students complete a conceptual design of an aircraft in a term-long project. Students are exposed to the aircraft design process, and must establish design specifications, develop and analyze alternative designs, and optimize their designs to meet mission requirements. Students work together in teams to apply material learned in the areas of aerodynamics, structures and materials, propulsion, stability and control, and flight mechanics and maneuvers to the preliminary design of an aircraft. The project requirements are selected to reflect real-life aircraft mission requirements, and teams are required to design systems which incorporate appropriate engineering standards and multiple realistic constraints. The teams present their design in a final report and oral presentation.
Recommended background: aerodynamics (AE 3711 or equivalent), aerospace structures (AE 3712 or equivalent), air breathing propulsion (AE 4711 or equivalent), aircraft dynamics and control (AE 4723 or equivalent).

AE 4771. SPACECRAFT AND MISSION DESIGN.
Cat. I
This course introduces students to design of spacecraft and missions. Students are introduced to the process of designing a spacecraft and major subsystems to meet a specific set of objectives or needs. In addition, students will learn about different spacecraft subsystems and what factors drive their design. Particular emphasis is given to propulsion, power, attitude control, structural, and thermal control subsystems. Students work together in teams to apply material learned in the areas of orbital mechanics, attitude determination and control, space structures, and propulsion to the preliminary design of a spacecraft and mission. The project requirements are selected to reflect real-life missions, and teams are required to design systems which incorporate appropriate engineering standards and multiple realistic constraints. The teams present their design in a final report and oral presentation.
Recommended background: astronautics (AE 2713 or equivalent), rocket propulsion (AE 4719 or equivalent), spacecraft dynamics and control (AE 4713 or equivalent).

AIR FORCE AEROSPACE STUDIES

AS 1001. THE FOUNDATIONS OF THE UNITED STATES AIR FORCE I.
Cat. I (1/9 unit)
The AS 1000 sequence of courses are designed to introduce students to the United States Air Force and Air Force Reserve Officer Training Corps. Featured topics include mission and organization of the Air Force, officership and professionalism, Air Force officer opportunities, military customs and courtesies, and an introduction to communication skills.
The first course focuses on the foundation of officership and customs and courtesies.
The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 1001 Leadership Laboratory includes a study of Air Force customs and courtesies, drill and ceremonies, and military commands.

AS 1002. THE FOUNDATIONS OF THE UNITED STATES AIR FORCE II.
Cat. I (1/9 unit)
The AS 1000 sequence of courses are designed to introduce students to the United States Air Force and Air Force Reserve Officer Training Corps.
A continuation of AS 1001, the second course in this series emphasizes those communication skills needed in today's Air Forc e. It describes the communication systems as well as discusses common barriers and enhancements to effective communications. The course includes numerous speaking and written exercises using current Air Force topics.
The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 1002 Leadership Laboratory includes a study of Air Force customs and courtesies, drill and ceremonies, and military commands.

AS 1003. THE FOUNDATIONS OF THE UNITED STATES AIR FORCE III.
Cat. I (1/9 unit)
The AS 1000 sequence of courses are designed to introduce students to the United States Air Force and Air Force Reserve Officer Training Corps.
A continuation of AS 1002, the course outlines the origin of the Air Force and the organizational structure of the Air Force with a focus on the missions of select military organizations. The basic history of the United States military is studied in order to appreciate how military history impacts the Air Force today. Written and oral communication skills are practiced.
The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 1003 Leadership Laboratory includes a study of Air Force customs and courtesies, drill and ceremonies, and military commands.

AS 1004. THE FOUNDATIONS OF THE UNITED STATES AIR FORCE IV.
Cat. I (1/9 unit)
The AS 1000 sequence of courses are designed to introduced students to the United States Air Force and Air Force Reserve Officer Training Corps.
The final course in the AS 1000 sequence, it introduces students to the Air Force installation and her sister services. Written and oral communication skills are practiced.
The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 1004 Leadership Laboratory includes a study of Air Force customs and courtesies, drill and ceremonies, and military commands.

AS 2001. THE EVOLUTION OF USAF AIR AND SPACE POWER I.
Cat. I (1/9 unit)
The AS 2000 sequence of courses are designed to examine general aspects of air and space power through a historical perspective. Utilizing this perspective, the course covers a time period from the first balloons and dirigibles to the space-age global positioning systems of the Persian Gulf War. Historical examples are provided to extrapolate the development of Air Force capabilities (competencies), and missions (functions) to demonstrate the evolution of what has become today's USAF air and space power. As a whole, the AS 2000 sequence of courses provides the student with a knowledge level understanding for the general element and employment of air and space power.

The first course covers the factors leading to the early development of air power through the use of air power during World War II. The development of oral and written communication skills is continued from the AS 1000 classes.

The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 2001 Leadership Laboratory continues a study of Air Force customs and courtesies, drill and ceremonies, military commands, and preparation for Field Training.

AS 2002. THE EVOLUTION OF USAF AIR AND SPACE POWER II.
Cat. I (1/9 unit)
The AS 2000 sequence of courses are designed to examine general aspects of air and space power through a historical perspective. The second course in the series continues with the development of air power from World War II through the development of the Intercontinental Ballistic Missile.

The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 2002 Leadership Laboratory continues a study of Air Force customs and courtesies, drill and ceremonies, military commands, and preparation for field training.

AS 2003. THE EVOLUTION OF USAF AIR AND SPACE POWER III.
Cat. I (1/9 unit)
The AS 2000 sequence of courses are designed to examine general aspects of air and space power through a historical perspective. The third course in the series begins with a study of air power in the Vietnam war through the Gulf war. Oral and written communications skills will be practiced.

The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 2003 Leadership Laboratory continues a study of Air Force customs and courtesies, drill and ceremonies, military commands, and preparation for field training.

AS 2004. THE EVOLUTION OF USAF AIR AND SPACE POWER IV.
Cat. I (1/9 unit)
The AS 2000 sequence of courses are designed to examine general aspects of air and space power through a historical perspective. The course examines several fundamental truths associated with war in the third dimension: e.g. Principles of War and Tenets of Air and Space Power. As a whole, this course provides the students with a knowledge level understanding for the general element and employment of air and space power from an institutional, doctrinal and historical perspective. In addition, the students will continue to discuss the importance of the Air Force Core Values with the use of operational examples and historical Air Force leaders and will continue to develop their communication skills. The final course in the series explores the future of the Air Force through 2025.

The course includes one hour of class work and two hours of mandatory leadership laboratory per week. The AS 2004 Leadership Laboratory continues a study of Air Force customs and courtesies, drill and ceremonies, military commands, and preparation for field training.

AS 3001. AIR FORCE LEADERSHIP STUDIES I.
Cat. I (1/6 unit)
The AS 3000 sequence of courses is a study of leadership, management fundamentals, professional knowledge, Air Force personnel and evaluation systems, leadership ethics, and communication skills required of an Air Force junior officer. Throughout the courses, case studies are used to examine Air Force leadership and management situations as a means of demonstrating and exercising practical application of concepts being studied.

The first course explores different styles of leadership, followership, and management functions.

The course includes three hours of class work and three hours of mandatory leadership laboratory per week. The AS 3001 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-type activities and giving students the opportunity to apply leadership and management principles.

AS 3002. AIR FORCE LEADERSHIP STUDIES II.
Cat. I (1/6 unit)
The AS 3000 sequence of courses is a study of leadership, management fundamentals, professional knowledge, Air Force personnel and evaluation systems, leadership ethics, and communication skills required of an Air Force junior officer. The second course studies various aspects of leadership, conflict management, counseling, and supervision.

The course includes three hours of class work and three hours of mandatory leadership laboratory per week. The AS 3002 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-type activities and giving students the opportunity to apply leadership and management principles.

AS 3003. AIR FORCE LEADERSHIP STUDIES III.
Cat. I (1/6 unit)
The AS 3000 sequence of courses is a study of leadership, management fundamentals, professional knowledge, Air Force personnel and evaluation systems, leadership ethics, and communication skills required of an Air Force junior officer. The third course emphasizes teambuilding, process improvement, and military ethics.

The course includes three hours of class work and three hours of mandatory leadership laboratory per week. The AS 3003 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-type activities and giving students the opportunity to apply leadership and management principles.

AS 3004. AIR FORCE LEADERSHIP STUDIES IV.
Cat. I (1/6 unit)
The AS 3000 sequence of courses is a study of leadership, management fundamentals, professional knowledge, Air Force personnel and evaluation systems, leadership ethics, and communication skills required of an Air Force junior officer. The final course explores officer professional development, and personnel and evaluation systems including practical exercises.

The course includes three hours of class work and three hours of mandatory leadership laboratory per week. The AS 3004 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-type activities and giving students the opportunity to apply leadership and management principles.

AS 4101. NATIONAL SECURITY AFFAIRS I.
Cat. I (1/6 unit)
The AS 4000 sequence of courses examines the national security process, regional studies, advanced leadership ethics, and Air Force doctrine. Special topics of interest focus on the military as a profession, officership, military justice, civilian control of the military, preparation for active duty and current issues affecting military professionalism. Throughout the AS 4000 sequence of courses, briefing and writing exercises will be accomplished with emphasis on refining communication skills.

The first course examines in depth the national security process, principles of war and the Air Force major commands.

The course includes three hours of class work and three hours of mandatory leadership laboratory each week. The AS 4101 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-like activities and giving the students the opportunity to apply leadership and management principles.

AS 4102. NATIONAL SECURITY AFFAIRS II.
Cat. I (1/6 unit)
The AS 4000 sequence of courses examines the national security process, regional studies, advanced leadership ethics, and Air Force doctrine. The second course provides a detailed examination of Air Force doctrine including a study of the joint doctrine and the roles of the other military services.

The course includes three hours of class work and three hours of mandatory leadership laboratory each week. The AS 4102 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-like activities and giving the students the opportunity to apply leadership and management principles.

AS 4103. NATIONAL SECURITY AFFAIRS III.
Cat. I (1/6 unit)
The AS 4000 sequence of courses examines the national security process, regional studies, advanced leadership ethics, and Air Force doctrine. The third course provides an extensive study of alliances and regional security issues, including international peacekeeping and terrorism. Continued attention is given to developing the research and communications skills necessary to be successful as junior officers.

The course includes three hours of class work and three hours of mandatory leadership laboratory each week. The AS 4103 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-like activities and giving the students the opportunity to apply leadership and management principles.

AS 4104. PREPARATION FOR ACTIVE DUTY.
Cat. I (1/6 unit)
The AS 4000 sequence of courses examines the national security process, regional studies, advanced leadership ethics, and Air Force doctrine. The final course in the series examines officership, the military justice system, social responsibilities, current issues affecting the military profession, and various factors that will facilitate a smooth transition from civilian to military life.

The course includes three hours of class work and three hours of mandatory leadership laboratory each week. The AS 4104 Leadership Laboratory complements the classroom work by providing advanced leadership experiences in officer-like activities and giving the students the opportunity to apply leadership and management principles.

ARCHITECTURAL ENGINEERING

AREN 2002. ARCHITECTURAL DESIGN I.
(Cat. I)
This course offers an introduction to the architectural design process by exploring the relations between materials, structures, spaces, and architectural composition. Studio: The studio design component explores the syntax of architecture, siting, context, and human scale. Students will engage these topics through architectural design studies for a project of limited scope and programmatic complexity. Hand drawing and sketching, modeling and visualization software, orthographic drawings, and physical models are used to explore, develop, and communicate architectural design concepts. Lectures / lab: The lecture/lab component of the course focuses on two-dimensional drawing techniques (including hand drawings and sketching), drawing conventions, and architectural representation techniques. Students are introduced to the fundamental uses of modeling software in engineering and architectural design practice. Advanced topics may include three dimensional modeling rendering, animation, and parametric design.

This course uses studio, lecture, and lab based teaching methods

Recommended background: None

AREN 2004. ARCHITECTURAL DESIGN II – LIGHT AND LIGHTING SYSTEMS.
Cat. I
This course aims to develop an understanding of the role of light and lighting in the perception of architecture and human well-being. Studio: The studio component of the course will explore the interactions between light, materials, spaces, and people. Students will engage these topics through architectural design studies for a project with well- specified lighting and architectural needs. Modeling, visualization and simulation software, orthographic drawings, and physical models are used to explore and analyze architectural design concepts. Lectures: The lecture components of the course focuses on the design of illumination systems in buildings. A general introduction to the visual environment is provided, including subjective and objective scales of measurement, visual perception, photometry, brightness, luminance, illumination, natural and artificial lighting. Other topics include photometric units, light sources, daylight luminaries, lighting quality, light loss factors, average luminance calculations (lumen method), point-by-point calculations, performance impacts, and ethics. Field measurements and computer simulations are used to explore some major aspects of architectural illumination systems. Design problems are solved by considering economic evaluation, energy saving criteria and applicable standards and building codes. Students will be introduced to the use of computer tools for the design, analysis, and visualization of natural and artificial lighting in buildings.

This course uses studio and lecture based teaching methods

Recommended background: Introductory architectural design (AREN 2002 or equivalent).

Students may not receive credit for both AREN 2004 and AREN 3005

AREN 2023. INTRODUCTION TO ARCHITECTURAL ENGINEERING SYSTEMS.
Cat. I
The objective of this course is to introduce the functional parts and systems that make up a building as well as their interactions in delivering required sustainable performance. It encompasses foundations, structures, building enclosures, heating and air conditioning, electrical, plumbing and fire safety systems as well as concepts of building performance and aspects of pertinent building codes and standards. This course, in addition, incorporates basic principles of building science and green construction.

AREN 2025. BUILDING ELECTRICAL SYSTEMS.
Cat. I
The principles of electrical system design in buildings are introduced in this course. Starting with an overview of electrical fundamentals and related laws, it covers circuit design, power distribution and service equipment, communication systems and special electrical systems that meet the requirements of the national electric code as well as building occupants. Other topics include single-phase and three-phase circuits, electrical and lighting loads, panel-board design, switching, system sizing, grounding, fault calculations, and over-current protection. The design criteria and calculation procedures for developing simple layouts of building electrical systems are illustrated. Work includes study of applicable NFPA 70 (NEC) and related building codes.

Recommended background: electricity and magnetism (PH 1120/1121 or equivalent)

AREN 3002. ARCHITECTURAL DESIGN III.
Cat. I
This course aims to further a student's knowledge of the architectural design process through study of ideas, principles and methods of design and construction. Studio: Architectural concepts are developed with the completion of a project of expanded scope and complexity. The course emphasizes the development of form, space, spatial relationships, materials, context, program, and architectural presentation techniques. Hand drawing and sketching, modeling and visualization software, orthographic drawings, detail drawings, and physical models are used to explore, develop, and communicate architectural design concepts. Lectures: The lecture/lab component of the course focuses on three-dimensional modeling and architectural representation techniques. Students are introduced to advanced modeling software in engineering and architectural design practice. Topics include three dimensional modeling, rendering, animation, and parametric design.

This course uses studio, lecture, and lab based teaching methods

Recommended background: Intermediate architectural design (AREN 2002 and AREN 2004 or equivalent)

AREN 3003. PRINCIPLES OF HVAC DESIGN FOR BUILDINGS.
Cat. I
The course introduces principles and applications of mechanical systems that are required for environmental comfort, health, and safety of building occupants with a focus on energy efficiency and conservation. Topics include psychometrics, thermal comfort, building heating and cooling loads, fluid flow basics, HVAC components and systems, building envelop heat transfer, and energy requirements. In the course, students develop the ability to design and conduct computational modelling experiments and to analyze and interpret output data for selection between system alternatives in order to optimize energy use.

Recommended background: Thermodynamics.

Some sections of this course may be offered as Writing Intensive (WI)

AREN 3006. ADVANCED HVAC SYSTEM DESIGN.
Cat. I
Analysis of heating and cooling load requirements, considering building construction type, geometry, infiltration, occupancy effects, and daily load variations. Heating design addresses water heating systems, electrical heating, central heating, heating of low and high-rise buildings, selection of heaters, boilers, pumps, piping design. Cooling design addresses refrigerants, refrigeration cycle, evaporator, compressor, condenser, thermostatic expansion valves, refrigeration system control equipment, motor and motor control equipment, refrigeration accessories, calculation of refrigeration piping and absorption systems. Computer applications for heating and cooling load analysis will be introduced to develop energy saving solutions. Analytical techniques and building codes are discussed through case studies and design projects.

Recommended background: AREN 3003, ES 3004.

AREN 3020. ARCHITECTURAL DESIGN IV – BUILDING ENERGY SIMULATION.
Cat. I
This course aims to develop an understanding of sustainability in architecture and introduces the fundamentals and applications of energy simulation tools. Studio: The studio component of the course will explore the relationships between people, buildings, and the environment. Students will explore the impact of building site and context, orientation, building massing and envelop configuration, occupancy and other factors. Students will engage these topics through architectural design studies and simulations for a project of increased scope and programmatic complexity. Modeling and visualization software, simulation tools, orthographic drawings, and physical models are used to explore and develop architectural design concepts. Lectures: The lecture components of the course focuses on the principles of building energy simulation, with a focus on the practical applications of building energy simulation tools to building design. Topics being covered include various model input parameters such as building geometry, orientation, climate, comfort, zoning, material properties, operation schedules, and HVAC systems. Building energy simulation software is illustrated and applied to the analysis of case studies and/or design projects. Simulation output results are critically analyzed and compared to the results obtained from other building energy calculation methods.

This course uses studio and lecture based teaching methods

Recommended background: Building Physics and HVAC system design (AREN 3024 and AREN 3003) and Architectural Design (AREN 2002, AREN 2004, and AREN 3002 or equivalent).

Students may not receive credit for both AREN 3020 and AREN 3025

AREN 3022. ARCHITECTURAL DESIGN V – BUILDING ENVELOPE DESIGN.
Cat. I
This course aims to develop an understanding of the architectural design development process with special focus on the design and detailing of building envelopes. Studio: Through an iterative process, students will advance the architectural and technical development of an architectural project of increased complexity. Modeling and simulation software, orthographic drawings, detail drawings, and physical models are used to advance the development of architectural design concepts. Lectures: The lecture component of the course covers the basic principles of building envelope design, focusing primarily on functional performance requirements and practical constructability aspects. Various building envelope systems are reviewed, including façade and roofing systems made of masonry, stone, concrete, timber, glass, and various metals. More elaborate building envelope strategies will also be reviewed; such as double skin facades and passive solar design approaches. Students will be introduced to computer tools and other methods for the analysis of heat and moisture transfer within building envelopes and components thereof.

This course uses studio and lecture based teaching methods

Recommended background: Building Physics and HVAC system design (AREN 3024 and AREN 3003) and Architectural Design (AREN 2002, AREN 2004, and AREN 3002 or equivalent).

Students may not receive credit for both AREN 3022 and AREN 3026

AREN 3024. BUILDING PHYSICS.
Cat. I
The course introduces the principles of building physics, as they are applied to various building design situations and performance requirements. Covered topics include heat transfer, moisture control, condensation, cold bridging, external and internal gains, and air flows, as they pertain to building envelopes (external walls, windows and doors, and roofs) and the requirements of environmental comfort of space occupants. Design exercises take into account pertinent building and energy codes as well as comfort standards. The course gives students the tools to integrate engineering science fundamentals and physics principles in developing building design solutions. Thermal measurements in building components are performed.

Recommended background: thermodynamics and heat transfer (ES 3001, ES 3003 or equivalent).

BASIC SCIENCES

GEOSCIENCES (GE)

GE 2341. GEOLOGY.
Cat. I
Students of this course will examine the fundamental principles of physical geology including the materials, structures, and surface features of the earth and the processes which produced them. Emphasis will be placed on the interrelationship of people and environment and applications to various fields of technology. The course includes field trips and a significant laboratory component.

BIOINFORMATICS AND COMPUTATIONAL BIOLOGY

BCB/BB 1003. EXPLORING BIOINFORMATICS AND COMPUTATIONAL BIOLOGY.
Cat.I
Life scientists are generating huge amounts of data on many different scales, from DNA and protein sequence, to information on biological systems such as protein interaction networks, brain circuitry, and ecosystems. Analyzing these kinds of data requires quantitative knowledge and approaches using computer science and mathematics. In this project-based course, students will use case studies to learn about both important biological problems and the computational tools and algorithms used to study them. Students will study a sampling of topics in the field; recent topics included complex disease genetics, HIV evolution, antibiotic resistance, and animal migration behavior. In addition, students will hear from several guest speakers about their interdisciplinary research. Computational tools explored will include both freely-available tools to analyze sequences and build phylogenetic trees (e.g. BLAST, MUSCLE, MEGA) as well as guided programming using languages such as Python, R, and Netlogo.

Students may not receive credit for both BCB / BB 100X and BCB / BB 1003.

BBT majors may count this course as fulfilling part of their quantitative science and engineering requirement, but not as part of their BB 1000 level course requirement.

Recommended background: High school biology. Programming experience is not required.

BCB/BB 3010. SIMULATION IN BIOLOGY.
Cat. II
Computer simulations are becoming increasingly important in understanding and predicting the behavior of a wide variety of biological systems, ranging from metastasis of cancer cells, to spread of disease in an epidemic, to management of natural resources such as fisheries and forests. In this course, students will learn to use a graphical programming language to simulate biological systems. Most of the classroom time will be spent working individually or in groups, first learning the language, and then programming simulation projects. We will also discuss several papers on biological simulations from the primary scientific literature. In constructing and comparing their simulations, students will demonstrate for themselves how relatively simple behavioral rules followed by individual molecules, cells, or organisms can result in complex system behaviors.

Recommended background: Students taking this course must have a solid background in a biological area they would like to simulate, at about the depth provided by a BB 3000 level class. No programming experience is assumed.

This course will be offered in 2020-21, and in alternating years thereafter.

BCB 4001/BB4801. BIOINFORMATICS.
Cat. II
In an age when the amount of new biological data generated each year is exploding, it has become essential to use bioinformatics tools to explore biological questions. This class will provide an understanding of how we organize, catalog, analyze, and compare biological data across whole genomes, covering a broad selection of important databases and techniques. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions in such areas as genetic sequence and protein structure comparisons, phylogenetic tree analysis, and

gene expression and biological pathway analysis. In addition, the course will provide students with an introduction to some of the theory underlying the software (for example, how alignments are made and scored).

Recommended background: a working knowledge of concepts in genetics and molecular biology (BB2920 and BB2950 or equivalent), and statistics (MA 2610 or MA2611 or equivalent)

This course will be offered in 2020-21, and in alternating years thereafter.

BCB 4002/CS 4802. BIOVISUALIZATION.
Cat. II
This course will use interactive visualization to model and analyze biological information, structures, and processes. Topics will include the fundamental principles, concepts, and techniques of visualization (both scientific and information visualization) and how visualization can be used to study bioinformatics data at the genomic, cellular, molecular, organism, and population levels. Students will be expected to write small to moderate programs to experiment with different visual mappings and data types.

Recommended background: CS 2102 or CS 2103, CS 2223, and one or more biology courses.

This course will be offered in 2020-21, and in alternating years thereafter.

BCB 4003/CS 4803. BIOLOGICAL AND BIOMEDICAL DATABASE MINING.
Cat. II
This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining.

Recommended Background: CS 2102 or CS 2103, CS 2223, MA 2610 or MA 2611, and one or more biology courses.

This course will be offered in 2019-20, and in alternating years thereafter.

BCB 4004/MA 4603. STATISTICAL METHODS IN GENETICS AND BIOINFORMATICS.
Cat. II
This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees.

Recommended background: MA 2612, MA 2631 (or MA 2621), and one or more biology courses.

This course will be offered in 2019-20, and in alternating years thereafter.

BIOLOGY AND BIOTECHNOLOGY

BB 1001. INTRODUCTION TO BIOLOGY.
Cat. I
This course is designed for students seeking a broad overview of biologic concepts, especially at the cell and organism level. It is conducted in an active style including the use of case studies, class discussion/participation, and classroom polling systems. The major goal of this course is to help students become more informed citizens, skeptical when presented with data in the media, and knowledgeable enough to question and make informed decisions about scientific advances and science policy. It will primarily focus on current topics which may include stem cells, ethical uses of DNA, development of personalized medicine, genetic engineering, antibiotic resistance. This course is intended for non-life-science majors. This will not fulfill a major distribution requirement for BBT majors.

Recommended background: high school biology

BB 1002. ENVIRONMENTAL BIOLOGY.
Cat. I
This course is designed for students seeking a broad overview of ecological systems and the effect of humans on the ecosystems. It provides an introduction to natural ecosystems, population growth, and the interaction between human populations and our environment. It is conducted in an active style including the use of case studies, class discussion/participation, and classroom polling systems. The major goal of this course is to help students become more informed environmental citizens, skeptical when presented with data in the media, and knowledgeable enough to question and make informed decisions about the environment. It will primarily focus on current topics but areas of discussion likely to be covered include ecosystems, populations, biodiversity, pollution, environmental economics and climate change.

This course is intended for non- life-science majors. This will not fulfill a major distribution requirement for BBT majors.

Recommended background: high school biology

BB/BCB 1003. EXPLORING BIOINFORMATICS AND COMPUTATIONAL BIOLOGY.
Cat.I
Life scientists are generating huge amounts of data on many different scales, from DNA and protein sequence, to information on biological systems such as protein interaction networks, brain circuitry, and ecosystems. Analyzing these kinds of data requires quantitative knowledge and approaches using computer science and mathematics. In this project-based course, students will use case studies to learn about both important biological problems and the computational tools and algorithms used to study them. Students will study a sampling of topics in the field; recent topics included complex disease genetics, HIV evolution, antibiotic resistance, and animal migration behavior. In addition, students will hear from several guest speakers about their interdisciplinary research. Computational tools explored will include both freely-available tools to analyze sequences and build phylogenetic trees (e.g. BLAST, MUSCLE, MEGA) as well as guided programming using languages such as Python, R, and Netlogo.

Students may not receive credit for both BCB / BB 100X and BCB / BB 1003.

BBT majors may count this course as fulfilling part of their quantitative science and engineering requirement, but not as part of their BB 1000 level course requirement.

Recommended background: High school biology. Programming experience is not required.

BB 1025. HUMAN BIOLOGY.
Cat. I
This course presents students with an introduction to general concepts of human biology with particular focus on human structure and function. Concepts such as homeostasis, structure/function, and regulatory systems will be introduced. Discussion of current topics related to human health, such as personalized medicine and recent advances in cancer research and auto immune disease will be integrated throughout the course. This course is intended for BBT and other life science majors.

Recommended background: a solid working knowledge of biological principles such as would be learned in a rigorous high school biology course.

BB 1035. BIOTECHNOLOGY.
Cat. I
Through lectures, discussion and project work, students will gain an understanding of the function of biological systems at the molecular and cellular level. This course will explore topics such as genes-to-proteins, cell cycle regulation, genomics, and cell signaling as foundational concepts in genetic and cellular engineering, synthetic biology, stem cell generation, regenerative and personalized medicine and the production of therapeutic biologics. Projects will be designed to facilitate students' understanding of the links between biological systems and biotechnology applications, including their impact on society. This course is intended for BBT and other life science majors.

Recommended background: a solid working knowledge of biological principles such as would be learned in a rigorous high school biology course.

BB 1045. BIODIVERSITY.
Cat. I
Through lectures, readings, and discussions this course will examine the breadth, patterns, mechanisms, and conservation of biodiversity. Case studies and peer-to-peer learning will be used to examine threats to regional and global biodiversity and assess management and engineering strategies for solutions to the biodiversity crisis. Students will investigate and interpret past and contemporary research to quantify, document, and track trends in biodiversity. This course will use problem sets and assignments to explore the natural, social, and economic tradeoffs associated with threats to and conservation of biodiversity. Students will develop an area of expertise and synthesize their comprehension of topics through project work (e.g., management plan, report, presentation, citizen science). Finally, this course will provide a synthesis of the interdisciplinary nature of biodiversity conservation and how principles of conservation biology, landscape ecology, metapopulation biology, and biogeography can be applied to strategies aimed towards sustaining Earth's biota. This course is intended for BBT and other life science majors.

Recommended Background: a solid working knowledge of biological principles such as would be learned in a rigorous high school biology course.

BB 2003. FUNDAMENTALS OF MICROBIOLOGY.
Cat. I
This course will introduce the basic principles of microbiology through lectures, discussion, readings, and projects. The course will explore both the fundamental biology of microbes and the ways in which microbes influence society and the world. Topics will include the morphology, physiology, and genetics of unicellular organisms with a primary focus on bacteria. Special attention will be given to organisms known to have important roles in health, research, industry, and the environment. This course is designed for all biology majors and other students who seek a good general education in modern biology.

Recommended background: A basic understanding of cell biology and elementary biochemical processes (BB 1035, BB 2550 or equivalent).

BB 2030. PLANT DIVERSITY.
Cat. I
This course focuses on general biological concepts as they relate to the vast array of plant species and their taxonomic links. Current uses of major plant phyla in both society and the biotechnology industry will be explored. Some emphasis will be given to economically important species chosen from agronomic and non-agronomic situations.

Recommended background: a working knowledge of concepts in biodiversity (BB 1045 or equivalent)

Students may not receive credit for both BB 2030 and BB 1040.

BB 2040. PRINCIPLES OF ECOLOGY.
Cat. I
This course is intended to help students understand ecological concepts at different levels of integration, from individuals to ecosystems, and the linkages among them. Students will also practice the application of qualitative and quantitative models to ecological systems and processes, as well as hypothesis generation, experimental design, and analysis and interpretation of data. In a format that includes team-based case studies, discussion and presentations, and ecological simulations, students will explore topics in both basic and applied ecology, which may include population ecology, host-parasite ecology and epidemiology, climate change, and sustainable agriculture, among others.

Recommended background: a working knowledge of concepts in biodiversity (BB 1045 or equivalent) and integral and differential calculus

BB 2050. ANIMAL BEHAVIOR.
Cat. I
This course will provide an introduction to the scientific study of animal behavior. A combination of lecture, reading, and video will be used to illustrate how proximate and ultimate forces interact to shape animal behavior in complex and fascinating ways. Behavioral phenomena in all members of the animal kingdom will be discussed and analyzed from ecological, evolutionary, cognitive, and neurobiological perspectives to highlight how the use of an integrative approach has greatly accelerated our ability to solve complex behavioral problems. Primary scientific literature will be used to outline experimental tools and techniques used to investigate behavior in different contexts, including communication, foraging, navigation, mate choice, predation, and social behavior.

BB 2550. CELL BIOLOGY.
Cat. I
The goal of this course is to help students to develop a working understanding of the unifying concepts that define cell structure and function including replication, metabolism, regulation, communication and death. Applications in therapeutics, molecular medicine, and genetic engineering will be introduced. Classic and current research examples will provide practice in hypothesis generation and testing as well as making clear the importance of a working knowledge of cell biology to support advances in biotechnology and medicine. The course serves as the foundation of all fields of modern biology, and is recommended for all BBT and other life science majors.

Recommended background: a working knowledge of concepts in biotechnology (BB 1035 or equivalent)

BB 2920. GENETICS.
Cat. I
Through interactive lectures, group problem solving, and analysis of primary scientific literature, this course will help students understand the gene concept and its application in modern biological analysis. This course will cover patterns of inheritance, the relationship between genotype and phenotype, and the transmission, coding, and expression of genetic information contained in DNA, in several model systems. Students will gain an understanding of the modern tools of genetic analysis, including gene cloning, creation of transgenic organisms, high-throughput sequencing and RNA interference. Applications of genetic analysis to current advancements in agriculture through crop improvements, and in human health, including gene therapy and personalized medicine, will be explored.

Recommended background: a working knowledge of concepts in biotechnology (BB 1035 or equivalent)

BB 2950. MOLECULAR BIOLOGY.
Cat. I
Through a combination of lectures and in class discussion, students will learn and understand the essential concept of molecular biology, including the mechanisms by which information stored in nucleic acids is maintained and processed in living systems. An evolutionary framework will help illustrate how genomes are structured and how they change. Basic regulatory mechanisms of gene expression will be addressed, with emphasis in eukaryotic gene regulatory proteins. The concepts learned in this course will provide the foundation to continue exploring this rapidly expanding field.

Recommended background: a working knowledge of concepts in biotechnology (BB 1035 or equivalent)

BB 3003. MEDICAL MICROBIOLOGY: PLAGUES OF THE MODERN WORLD, A CASE STUDY APPROACH.
Cat. I
Using a case study approach, this course will focus on molecular mechanisms of pathogenesis of a wide range of infectious diseases and host-pathogen interactions including a survey of human immunobiology. Students will gain an understanding of microbes that are of medical relevance including bacteria, viruses, fungi, and protozoans, enabling them to make informed decisions about appropriate medical interventions. Students will be able to evaluate how their day-to-day choices impact public health as well as alter microbial communities. This interactive course is designed for all biology and biochemistry majors as well as other students with the recommended background who have an interest in the pathogenesis of disease. .

Recommended background: a working knowledge of concepts in biotechnology, molecular biology and microbiology (BB 1035, BB 2950, and BB 2003 or equivalent)

Students may not receive credit for both BB 2002 Microbiology: Plagues of the Modern World and BB 3003.

BB/BCB 3010. SIMULATION IN BIOLOGY.
Cat. II
Computer simulations are becoming increasingly important in understanding and predicting the behavior of a wide variety of biological systems, ranging from metastasis of cancer cells, to spread of disease in an epidemic, to management of natural resources such as fisheries and forests. In this course, students will learn to use a graphical programming language to simulate biological systems. Most of the classroom time will be spent working individually or in groups, first learning the language, and then programming simulation projects. We will also discuss several papers on biological simulations from the primary scientific literature. In

constructing and comparing their simulations, students will demonstrate for themselves how relatively simple behavioral rules followed by individual molecules, cells, or organisms can result in complex system behaviors.

Recommended background: Students taking this course must have a solid background in a biological area they would like to simulate, at about the depth provided by a BB 3000 level class. No programming experience is assumed.

This course will be offered in 2020-21, and in alternating years thereafter.

BB 3050. CANCER BIOLOGY.

Cat.I

In this course, students will learn and apply advanced cellular and molecular biology concepts to understand causes and consequences of cancer cell transformation. Through an integration of primary literature and lecture material students will explore how research into basic mechanisms of cancer biology is used to identify therapeutic targets, and inform drug design. This course will cover discussion of the hallmarks of cancer including the deregulation of cell growth, cell death, and metabolism; corruption of genome stability, evasion of immune response, and metastatic potential.

Recommended background: A thorough understanding of genetics (BB 2920 or equivalent), molecular biology (BB 2950 or equivalent), and cell biology (BB 2550 or equivalent).

BB 3080. NEUROBIOLOGY.

Cat. I

The nervous system underlies every aspect of our behavior, including sensation, movement, emotion, and cognition. In this course, students will develop an understanding of neurobiology at several levels, from the physiology of individual neurons, through the functioning of neural circuits, and finally to the behavior of neural systems such as vision, motion, and memory. The class will be based on lectures accompanied by in-class activities, and will include weekly discussion of a paper from the scientific literature. The class will focus each year on a guiding theme, such as a particular neurotransmitter system, and will emphasize research on human neurological problems, such as schizophrenia, addiction, Alzheimer's disease, and autism.

Recommended background: a working knowledge of concepts in cell biology (BB 2550 or equivalent), and either genetics or molecular biology (BB2920 or BB2950 or equivalent)

Suggested background: a working knowledge of concepts related to the anatomy and physiology of movement and communication (BB 3101 or equivalent).

Students may not receive credit for both BB 4080 and BB 3080.

BB 3101. HUMAN ANATOMY & PHYSIOLOGY: MOVEMENT AND COMMUNICATION.

Cat. I

The form and function of the systems that are responsible for the support, movement, internal communication, and interaction of the human body with its environment will be presented and discussed: Integumentary, Skeletal, Muscular, Nervous (including the senses), and Endocrine.

Recommended background: BB 1025 and BB 2550.

Suggested background: Concurrent Laboratory Module: BB 3511. Students who have received credit for BB 2130 may not take BB 3101 for credit.

BB 3102. HUMAN ANATOMY & PHYSIOLOGY: TRANSPORT AND MAINTENANCE.

Cat. I

The form and function of the systems of the human body that provide for the intake, distribution, and processing of nutrients, water, and oxygen, and the systems that safeguard health by elimination of wastes, regulation of metabolism, and surveillance against disease will be presented and discussed. Digestive, Respiratory, Circulatory, Lymphatic, Endocrine, Urinary, and Reproductive.

Recommended Background: BB 1025 and BB 2550; CH 1010 and CH 1020.

Suggested background: Concurrent Laboratory Module: BB 3514. Students who have received credit for BB 3110 may not take BB 3102 for credit.

BB 3120. PLANT PHYSIOLOGY.

Cat. II

This course explores the remarkable physiology of plants and emphasizes their importance in past and future life on earth. Conserved and unique aspects of plant cellular physiology will provide the foundation to understand the challenges of life on land and multicellularity. Topics such as water relations, mineral nutrition, intra- and inter-cellular transport, photosynthesis, and light responses will be discussed. Examples from the recent literature will be used to illustrate some of the key existing problems in plant physiology.

Recommended background: a working knowledge of concepts in biodiversity and cell biology (BB 1045 and BB 2550 or equivalent) and in chemical reactions (CH 1020 or equivalent)

This course will be offered in 2019-20, and in alternating years thereafter.

Some sections of this course may be offered as Writing Intensive (WI).

BB 3140. EVOLUTION: PATTERN AND PROCESS.

Cat. II

In this course, students will explore the foundations of micro- and macro-evolutionary theory and will learn to apply these fundamental evolutionary principles through critical analysis of the primary scientific literature. In a course format that emphasizes team-based case studies, discussion of recent and classic papers, and computer simulation of evolutionary processes, students will explore the evolutionary foundations of a wide range of biological disciplines, and will gain experience in critical evaluation of approaches, arguments, and points of view in the field. Topics may include the history of life on Earth; biogeography and the origins of biodiversity; host-pathogen coevolution; and genomic and molecular evolution, among others.

Recommended background: a working knowledge of the principles of ecology and genetics (BB2040 and BB2920 or equivalent) and integral and differential calculus

This course will be offered in 2019-20, and in alternating years thereafter.

BB 3620. DEVELOPMENTAL BIOLOGY.

Cat. II

Through lecture, reading, and discussion, this course will help students understand how developmental biologists study the development of a fertilized egg into a multi-cellular animal. Beginning with the description of developmental events, the major problems of developmental biology such as determination of cell fate, differentiation, and pattern formation will be explored. Emphasis will be placed on techniques such as analysis of mutations, molecular genetics, gene transfer, and the use of model organisms. Societal implications of the ability to control the outcome of development will be discussed.

Recommended background: a working knowledge of concepts in microbiology, cell biology and genetics (BB 2002, BB 2550, and BB 2920 or equivalent)

This course will be offered in 2019-20, and in alternating years thereafter.

BB 3920. IMMUNOLOGY.

Cat. I

Through lecture, reading, and discussion, this course will help students understand the origin of immune cells in bone marrow development, the distinction between innate and adaptive immunity, and the function of the immune system in health and disease. The mechanisms responsible for the exquisite specificity of the adaptive immune system will be described. Throughout the course, the probable paths of evolution of the immune system will be stressed. As examples of major genetic diseases of immunity, case studies will be discussed on a weekly basis.

Recommended background: a working knowledge of the concepts in cell biology, genetics and biochemistry (BB 2550, BB 2920, CH 4110 and 4120 or equivalent)

BB/CH 4190. REGULATION OF GENE EXPRESSION.

Cat. I

Through lectures, problem sets, reading and discussion, and presentations this course will help elucidate for students the processes that allow regulated gene expression, mechanisms used in each type of regulation, and methods and techniques used for investigation of regulatory mechanisms. Readings from the current original research literature will explore the growing use of model systems and "omics" level approaches to enhance our ever expanding understanding of the gene regulatory mechanisms. The development of cell-based therapeutics and genetic engineering as they relate to gene regulation will be introduced.

Recommended background: a working knowledge of concepts in biochemistry and molecular genetics (CH 4110, 4120, 4130 and BB 4010 or equivalent)

BB 4260. SYNTHETIC BIOLOGY.

Cat.II

Do we yet have the technology to engineer life? Can we control gene expression to create organisms that function in useful ways? Do we understand the tenets of genetic regulation as well as we think we do? These important questions and more are investigated by the emerging field of Synthetic Biology. In this course, students will explore this exciting new realm of biology through in-depth analysis and discussion of primary literature. Topics to be covered include the design and construction of synthetic gene circuits, synthesis of new genes and genomes, logic gate regulation of gene expression, and the latest applications of synthetic biology to advances in medicine, information processing, and the environment.

Recommended Background: Students should have a strong foundational knowledge of cell biology, molecular biology, and genetics, as would be obtained from BB2550, BB2920, and BB2950.

This course will be offered in 2020-21, and in alternating years thereafter.

BB 4801/BCB 4001. BIOINFORMATICS.
Cat. II
In an age when the amount of new biological data generated each year is exploding, it has become essential to use bioinformatics tools to explore biological questions. This class will provide an understanding of how we organize, catalog, analyze, and compare biological data across whole genomes, covering a broad selection of important databases and techniques. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions in such areas as genetic sequence and protein structure comparisons, phylogenetic tree analysis, and gene expression and biological pathway analysis. In addition, the course will provide students with an introduction to some of the theory underlying the software (for example, how alignments are made and scored).

Recommended background: a working knowledge of concepts in genetics and molecular biology (BB2920 and BB2950 or equivalent), and statistics (MA 2610 or MA2611 or equivalent)

This course will be offered in 2019-20, and in alternating years thereafter.

BB 4900. CAPSTONE EXPERIENCE IN BIOLOGY AND BIOTECHNOLOGY.
Cat. I
These classes will serve as integrative experiences for students majoring in Biology & Biotechnology. The course will help students integrate concepts from other courses in the curriculum, practice skills of critical analysis, and evaluate and communicate scientific information effectively. The specific theme of each offering will center around a current topic of biological interest, and may include such areas as genomics, cancer, environmental problems, and synthetic biology. Prior to enrolling in the seminar, a student should have completed all of the BB course distribution requirements for BBT majors at the 1000 and 2000 level, or should seek advice from the course instructor.

Topics will be announced prior to registration in the year preceding the course offering.

IS4 BB. SPECIAL TOPICS.
Cat. I
Experimental courses, special conferences and seminars are offered by advance arrangement only.

BIOLOGY AND BIOTECHNOLOGY LAB COURSES

The lab activities in these courses will provide foundational skills needed for the study of living organisms and systems at the molecular, organismal and environmental level. In these labs students will begin building the skills to carry into more advanced labs, their MQPs and professional careers. In particular students will gain experience with scientific procedures and techniques, technical equipment, teamwork, laboratory safety, hypothesis generation and testing, scientific data analysis (including statistics), oral and written scientific communication and skills common to all areas of biology.

BB 2902. ENZYMES, PROTEINS, AND PURIFICATION.
Cat. I (1/6 unit)
This course gives basic practical experimental experience in enzymology, how enzymes work and how to purify them for later use. These techniques are the foundation the design and production of many therapeutic products. Examples of the types of techniques and experiences included in this course are:

- The action and optima of enzyme catalysis
- Induction of enzyme production
- Quantification and detection techniques for proteins
- Extraction and purification of protein from biological material using column chromatography
- Identification of compounds using Thin Layer Chromatography

Recommended background: a working knowledge of concepts in biotechnology (BB 1035 or equivalent).

BB 2903. ANATOMY AND PHYSIOLOGY.
Cat. I (1/6 unit)
This course is an active exploration of a number of topics in anatomy and physiology through the use of simulations, measurement and hands on discovery. It will be particularly relevant to any student considering a health related career, doing work where body structure is relevant or has interest in how body systems connect. A significant portion of this discovery will be accomplished by a hands-on dissection. Examples of the specific types of techniques and experiences included in this course are:

- Comparative and general anatomy of several organisms
- Physiology and function of body systems, processes and organs.
- Enzyme Linked Immunosorbent Assay (ELISA)
- Microscopy

Recommended background: a working knowledge of concepts in human biology (BB 1025 or equivalent).

BB 2904. ECOLOGY, ENVIRONMENT, AND ANIMAL BEHAVIOR.
Cat. I (1/6 unit)
This course examines topics in ecology and animal behavior through hands on experimentation and simulation. Activities in this course include interactions and observation of live animals as well as some outdoor activities and environmental sampling. This course will be relevant to students who have an interest in biology at more than the individual organism level as well as those with majors involving environmental and ecological concerns. Examples of the specific types of techniques and experience included in this course are:

- Observing, recording, understanding, and analyzing animal behaviors
- Handling of organisms
- Environmental and ecological assessment and sampling
- Observations of population dynamics

Recommended background: a working knowledge of concepts in biodiversity (BB 1045 or equivalent).

BB 2915. SEARCHING FOR SOLUTIONS IN SOIL: MICROBIAL AND MOLECULAR INVESTIGATIONS.
Cat. I (1/3 unit)
Students in this course will be part of a national student crowd sourcing initiative, developed in response to a decreasing supply of effective antibiotics and increased microbial resistance, to identify novel antibiotics produced by soil bacteria. Operating in an authentic research paradigm, students will gain skill in the process of scientific inquiry, including hypothesis generation and testing, and in common procedures of microbial culture and characterization. They will learn about and have the opportunity to use the techniques of recombinant DNA including the use of plasmids, restriction enzymes, and PCR. At the conclusion of the course students will report their findings in a poster style format and will be able to see the results of other groups around the country.

Recommended background: A familiarity with current topics in biotechnology or microbiology such as those introduced in BB 1035 and BB 2003, or equivalent.

Students may not receive credit for this course and either BB 2901 and BB 2905.

BB 2917. HUNTING FOR PHAGE.
Cat. I (1/3 unit)
Students in this course will become part of a national crowd sourcing initiative to isolate and identify novel bacteriophage. Students will design experiments to initially isolate phage (bacterial viruses) from environmental samples they have collected, then characterize and determine their DNA sequence. The DNA sequences will be used in the follow-on bioinformatics course BB 3526 Phage Hunters: The Analysis. Students in this course will make significant contributions to the field of genomics while gaining skill in the process of scientific inquiry, including hypothesis generation and testing, and practice in common microbiologic techniques.

Recommended background: A working knowledge of biotechnology or microbiology (BB 1035 or BB 2003, or equivalent).

Students enrolled in this course may wish to consider enrollment in BB 3526 (Phage Hunters: The Analysis).

Students that have already received course credit for BB 291X or BB 2916 may not also receive credit for BB 2917.

BB 3511. NERVE AND MUSCLE PHYSIOLOGY.
Cat. I (1/6 unit)
Exercises in this course focus on computer and wet laboratory studies of nerve and muscle structure and function. Students will gain experience in hypothesis generation and testing, and will have extensive experience using an interactive biomedical/physiological data acquisition and analysis system.
Recommended background: a working knowledge of laboratory skills and concepts in anatomy and physiology (BB 2903 and BB 3101 or equivalent).

BB 3512. MOLECULAR GENETICS LAB.
Cat. I (1/6 unit)
The topic of gene therapy will be used to give students experience with several fundamental skills in biotechnological research and practice: on-line information search and retrieval, computer cloning, and biological sequence analysis and manipulation. Course is entirely computer based.
Recommended background: a working knowledge of laboratory skills and concepts in molecular biology, microbiology and genetics (BB 2901, BB 2950, BB 2002, and BB 2920 or equivalent).

BB 3513. CELL CULTURE TECHNIQUES FOR ANIMAL CELLS.
Cat. I (1/6 unit)
Basic laboratory skills in mammalian cell culture to include cell counting, freezing and thawing cell lines, culture of suspension and attached cells.
Recommended background: BB 2901, BB 2550 and knowledge of aseptic techniques.
Concurrent or prior registration in BB 4008 is recommended.

BB 3514. CIRCULATORY AND RESPIRATORY PHYSIOLOGY.
Cat. I (1/6 unit)
Exercises in this course focus on wet laboratory and computer studies of circulatory and respiratory system structure, function and physiology. Students will gain experience in hypothesis generation and testing, and will be introduced to an interactive biomedical/physiological data acquisition and analysis system.
Recommended background: a working knowledge of laboratory skills and concepts in anatomy and physiology (BB 2903 and BB 3102 or equivalent).

BB 3517. FERMENTATION.
Cat. I (1/6 unit)
The experiments in this course focus on basic fermentation theory and practice, common to any bio-product production facility. Students will gain significant experience in hypothesis generation and testing as they work toward the goal of optimizing their proposed culture media.
Recommended background: a working knowledge of laboratory techniques in molecular biology, and microbiology (BB 2901 or equivalent), and concepts in cell biology (BB 2550 or equivalent).

BB 3519. PROTEIN PURIFICATION.
Cat. I (1/6 unit)
This is a laboratory course focusing on the theory and practice of protein purification from a primary source. Chromatographic techniques will include two more of the most commonly used in the biotech industry.
Recommended background: a working knowledge of laboratory skills in enzyme and protein purification, and concepts in biochemistry (BB 2902 and CH 4110 or equivalent).

BB 3521. MICROSCOPY.
Cat. II (1/6 unit)
Through a research-based laboratory and short lectures, students will learn the basic principles of image formation, resolution, and digital imaging. Students will develop confidence in the use of the light microscope and be able to apply different modes of microscopy to solve biological problems. This course emphasizes a quantitative approach to microscopy and digital imaging applied toward simple phenotypic analysis. Student will develop scientific writing skills and learn how to prepare professional quality images.
Recommended background: a working knowledge of laboratory techniques in molecular biology, and microbiology (BB 2901 or equivalent), and concepts in cell biology (BB 2550 or equivalent)
Some sections of this course may be offered as Writing Intensive (WI).

BB 3525. PLANT PHYSIOLOGY.
Cat. I (1/6 unit)
Basic studies in the biochemical and physical systems plants use to sustain life; includes an introduction to plant cell culture techniques.
Recommended background: BB 1045 and BB 2903.
Concurrent or prior registration in BB 3120 is recommended.
Students who have received credit for BB 325X may not receive credit for BB 3525.
Some sections of this course may be offered as Writing Intensive (WI).

BB 3526. PHAGE HUNTERS: THE ANALYSIS.
Cat. I (1/6 unit)
In this computer lab students will work with phage genomic sequences obtained from novel bacteriophages isolated in BB 2910, Phage Hunters: The Quest. The raw genome files will be finished and oriented; students will then search the sequence to identify and map existing genes and other genomic components (sequence annotation). Additional course goals are to do an initial comparative genomic analysis and post-annotation experimentation. The ultimate goal is to produce novel bacteriophage genome sequences that are ready to be submitted to GenBank, the US repository of DNA sequence information at the National Institute of Health.
Recommended background: a working knowledge of genome structure and function (BB 2920, BB 2950, or equivalent).
Students planning to take this course may wish to consider enrollment in BB 2916 (Phage Hunters: The Quest)
Students may not receive credit for both BB 350X and BB 3526

BB 3527. MOLECULAR BIOLOGY AND GENETIC ENGINEERING: APPROACHES AND APPLICATIONS.
Cat. I (1/3 unit)
In this laboratory based course, students will learn to use current techniques in molecular and genetic engineering to address authentic research questions. Students will design and execute experiments to assess hypotheses, and evaluate data relative to those hypotheses. Specific approaches may include the generation of novel plasmids, genes, and cells, designed to specifically address contemporary problems in biology and biomedical science. In each offering, the problem addressed will be selected from and the results contribute to current faculty research initiatives.
Recommended background: Working knowledge of the principles of molecular biology (BB 2950 or BB 2920 or equivalent) and cell biology (BB 2550 or equivalent), as well as relevant biology laboratory experience (BB 2905, BB 2915, or BB 2916).
Students may not receive credit for both BB 356X and BB 3527.

BB/CH 4170. EXPERIMENTAL GENETIC ENGINEERING.
Cat. I (1/3 unit)
This laboratory course focuses on modern DNA technologies and general applications of gene manipulation. Topics include gene amplification and recombination, promoter and plasmid engineering, gene expression and analysis, model systems, CRISPR, genomics and transgenics. Experiments in this course are integrated into an overall genetic engineering project throughout the term that will involve techniques such as electrophoresis, quantitative spectrofluorimetry, and real-time quantitative PCR. Methods of data analysis, common statistical approaches and technical writing will be emphasized throughout the course.
Recommended background: Knowledge of organic chemistry fundamentals as well as biochemical concepts including DNA replication and recombination, RNA synthesis and protein synthesis. Familiarity with cellular architecture is also recommended. See CH 2310, BB 2550 and CH 4110 or equivalent.

Graduate Biology and Biotechnology Courses of Interest to Undergraduates

The following courses are open to advanced undergraduates with special **written** permission of the course instructor and department head.

BB 501. SEMINAR.

BB 509. SCALE-UP OF BIOPROCESSING.
Strategies for optimization of bioprocesses for scale-up applications. In addition to the theory of scaling up unit operations in bioprocessing, students will scale-up a bench scale bioprocess (5 liters) including fermentation and downstream processing to 55 liters. Specific topics include the effects of scaling-up on: mass transfer and bioreactor design, harvesting techniques including tangential flow filtration and centrifugation, and chromatography (open column and HPLC).

Recommended courses include BB 3055 Microbial Physiology and BB 4070/560 Separations of Biological Molecules, as a working knowledge of the bench scale processes will be assumed. Otherwise, instructor permission is required.

BB 542. ECOLOGICAL SIMULATION MODELING.
This course will cover computer simulation modeling of populations, bioenergetics, behavior of individuals, and ecosystem dynamics. Modeling techniques covered will range from simple linear models of populations and interactions between ecosystem components to individual-based models of populations in complex environments. Students successfully completing the course should be capable of understanding models used in today's study of populations and ecosystems and of developing original models. Knowledge of a programming language is assumed.

BB 560. SEPARATION OF BIOLOGICAL MOLECULES.
This course provides a detailed hands-on survey of state-of-the-art methods employed by the biotechnology industry for the purification of products, proteins in particular, from fermentation processes. Focus is on methods which offer the best potential for scale-up. Included are the theory of the design as well as the operation of these methods both at the laboratory scale as well as scaled up. It is intended for biology, biotechnology, chemical engineering, and biochemistry students. A knowledge of basic biochemistry is assumed.

BB 565. VIROLOGY.
This advanced-level course uses a seminar format based on research articles to discuss current topics related to the molecular/cell biology of viral structure, function, and evolution. Particular emphasis is placed on pathological mechanisms of various human disorders, especially emerging diseases, and the use of viruses in research.

BB 570. SPECIAL TOPICS.
Specialty subjects are offered using the research expertise of the department faculty. Content and format varies to suit the interest and needs of the faculty and students. This course may be repeated for different topics covered.

BB 575. ADVANCED GENETICS & CELL BIOLOGY.
Topics in this course focus on the basic building blocks of life; molecules, genes and cells. The course will address areas of the organization, structure, function and analysis, of the genome and of cells. Required Background: Students in the course should be familiar with the fundamentals of recombinant DNA and molecular biological techniques as well as cell biology.

BB 576. ADVANCED INTEGRATIVE BIOSCIENCE.
This course concentrates on the organization of cells into biological systems and into individual organisms. Discussion will center on the development and function of specific model systems such as the nervous and immune systems. Required background: Students in the course should be familiar with the fundamentals of developmental biology, genetics and cell biology.

BB 577. ADVANCED ECOLOGICAL & EVOLUTIONARY BIOSCIENCE.
This course will explore the organization of individuals into communities, and the evolution of individual traits and behaviors. Problems discussed will range from those of population harvesting and the effect humans have on the environment to the evolution of disadvantageous traits. Required background: Students should be familiar with fundamentals of population interactions, evolution and animal behavior.

BB 578. ADVANCED APPLIED BIOTECHNOLOGY.
This course examines the use of biotechnological advances towards solving real world problems. Students will discuss problem-solving strategies from the current literature in the areas of medicine, agriculture, environmental protection/restoration and industrial biotechnology. Required background: Students should be familiar with biochemistry, microbiology, and plant and animal physiology.

BIOMEDICAL ENGINEERING

The second digit for Biomedical Engineering course numbers is coded as follows:

0 — Bioinstrumentation, Biosignals, Introduction
1 — Physiology
2 — Bioelectric, Bioimaging
3 — Design
4 — Communication
5 — Biomechanics, Biological Systems
6 — Biofluids
7 — Cellular and molecular
8 — Biomaterials

NOTE: Courses listed in previous catalogs with "BE" as the prefix and the same course number as below are considered to be the SAME COURSE.

BME 1001. INTRODUCTION TO BIOMEDICAL ENGINEERING.
Cat. I
This course uses lectures, demonstrations, projects and scientific literature readings on the major branches of biomedical engineering. A series of guest lectures, including device demonstrations introduce students to the many branches of biomedical engineering. Course work for BME 1001 is based on small, creative projects focusing on primary literature, department research, global health, and biomedical engineering as a whole.

BME 1004. INTRODUCTION TO PROGRAMMING IN MATLAB.
Cat. I
This course will introduce basic and essential programming skills in modern engineering program language, Matlab, to all BME students. The course will include basic programming syntax, control structures, data structures (vectors, matrices, structures, cell arrays), 2D images, 3D image volumes, string manipulations, File I/O, figure plotting/visualization, image display, and basic graphical user interface (GUI) design.

Recommended background: none.

NOTE: The course does not count for engineering credits, but will fulfill the computer programming requirement for BME students.

BME 2001. INTRODUCTION TO BIOMATERIALS.
Cat. I
This beginning course provides important background for all science and engineering disciplines regarding the capabilities and limitations of materials relevant to the development of medical devices. Students are introduced to the fundamental theme of materials science – structureproperty-processing relationships in biomaterials, specifically metals, ceramics, and plastics. Aspects of material structure range from the atomic to microstructural and macroscopic scales. In turn, these structural features determine the properties of materials. In particular, this course investigates connections between structure and mechanical properties, and how working and thermal treatments may transform structure and thus alter material properties. This knowledge is then applied to material selection decisions for the design of medical devices and engineered tissues.

Recommended background: prior knowledge of college-level chemistry and physics.

Students who have previously received credit for ES 2001 or BME 2811 may not receive credit for BME 2001.

BME 2210. BIOMEDICAL SIGNALS, INSTRUMENTS AND MEASUREMENTS.
Cat. I
This course is an introduction to the instrumentation methods used to measure, store and analyze the signals produced by biomedical phenomena. The goal of this course is to familiarize students with the basic design and implementation of techniques for measuring a broad scope of signal types for molecular, cellular and physiological research. Sensors used for acquiring electrical, magnetic, optical/spectral and chemical signals will be covered. Topics include the underlying physics and chemistry of biomedical signals, biosensor types and usage, amplification and signal conditioning, data acquisition methods, and sources of artifact and noise.

Recommended background: PH 1120/21, CH 1010 or equivalent.

BME 2211. BIOMEDICAL DATA ANALYSIS.
Cat. I
To learn the fundamentals of basic signal processing methods as well as linear time series analyses framework for modeling and mining biological data. Tools of data analysis include statistics for determining significance of a result, Laplace and Z transforms, convolution, correlation, sampling theorem, Fourier transform, transfer function, coherence function and various filtering techniques. The goal of this course is to offer the students an opportunity to learn and model and simulate static and dynamic physiological systems using linear systems theory. First principles of chemistry and physics are used to quantitatively model physiological systems. Most of the models are based on linear systems theory. Simulations and estimation are performed using Matlab and already-developed software.
Recommended background: BME 2210, CS 1004 or equivalent.

BME 2502. INTRODUCTION TO BIOMECHANICS: STRESS ANALYSIS
Cat. I
This is an introductory course that addresses the analysis of basic mechanical and structural elements relevant to biomechanics. Topics include general concepts of stresses, strains, and material properties of biomaterials and biological materials including viscoelasticity. Also covered are stress concentrations, two-dimensional stress transformations, principal stresses, and Mohr's circle. Applications are to uniaxially loaded bars, circular shafts under torsion, bending and shearing and deflection of beams. Both statically determinate and indeterminate problems are analyzed.
Recommended background: Differential (MA 1021) and integral (MA 1022) calculus, vector algebra (MA 1023), physics mechanics (PH 1110 or PH 1111), and statics (ES 2501). Students who have previously received credit for BME 2511 or ES 2502 may not receive credit for BME 2502.

BME 2610. INTRODUCTION TO BIOPROCESS ENGINEERING.
Cat. I
This course is an introduction to fundamental material and energy balances related to the field of Biomedical Engineering. The fundamentals of bioprocess engineering calculations and data analysis, and bioengineering processes and process variables will be covered. Students will learn to identify a system, define boundary conditions, and characterize the system processes to generate appropriate material and energy balances using the principles of conservation of mass and energy. Fundamentals and applications in the human body and biomanufacturing are examined. Specific examples may include an organ, multiple organs or the entire body, bioprocess instrumentation, individual or groups of cells, cell culture bioreactors, tissue engineered scaffolds, and drug delivery systems.
Recommended background: Basic knowledge of differential and integral calculus (e.g. MA 1021 and MA 1022 or equivalent), human biology (e.g., BB 1025 or equivalent), and chemistry (e.g. CH 1010 and CH1020 or equivalent).

BME 3111. PHYSIOLOGY AND ENGINEERING.
Cat. I
This course provides students with an understanding of mammalian physiology and the engineering aspects of different physiological systems. The course will have both a lecture and laboratory portion. The laboratory portion will provide the students with the ability to analyze and interpret data from living systems, which is a required ABET program criteria for student majoring in Biomedical Engineering. The course will focus on a number of organ systems that may include cardiovascular, respiratory, and renal. Engineering principles that include biomechanical, bioelectrical, and biofluids will be applied to physiological systems.
Recommended background: A knowledge of Cell Biology (such as BB 2550), biomechanics and biotransport (such as BME 2511), and signal analysis (such as BME 2210) or equivalent.

BME 3300. BIOMEDICAL ENGINEERING DESIGN.
Cat. I
Students are guided through the open-ended, real-world, design process starting with the project definition, specification development, management, team interactions and communication, failure and safety criteria, progress reporting, marketing concepts, documentation and technical presentation of the final project outcome. The course will include a significant writing component, will make use of computers, and hands-on design explorations.
Students who have previously received credit for BME 2300 may not receive credit for BME 3300.

BME 3610. TRANSPORT ANALYSIS IN BIOENGINEERING.
Cat. I
This course provides an overview of the modeling and analysis of fluid and mass transport processes related to the field of Biomedical Engineering and Bioprocess Engineering. Fundamentals and applications of hydrostatics, conservation of mass and momentum in modeling and analysis of biological fluid transport processes in the human body and bioprocess equipment are presented and discussed. It includes modeling and analysis of blood and biological fluid flow through blood vessels, capillary beds and bioprocess equipment. Modeling and analysis of diffusive and convective mass transport in biological conduits and membranes, selective permeability and nutrient/waste exchange in parenchymal tissues with transport barriers unique to biological systems such as intact and fenestrated endothelium. Basic concepts of pharmacokinetics such as plasma clearance, volume of distribution of drugs and other biological solutes in body tissues are also covered. Surface adsorption and membrane permeability concepts are covered in the context of biological soluted exchange in capillaries and bioprocess operations. Students may not receive credit for both BME 3610 and BME 361X.
Recommended background: Basic knowledge of differential and integral calculus (e.g., MA 2051 or equivalent), fundamental knowledge of biological system function or cell function (e.g., BB 1035 or BB 2550 or equivalent), fundamentals of data analysis and process modeling such as some of the topics covered in BME 2211 or BME 2610 or ChE 2011, or equivalent.

BME/ECE 4011. BIOMEDICAL SIGNAL ANALYSIS.
Cat. II
Introduction to biomedical signal processing and analysis. Fundamental techniques to analyze and process signals that originate from biological sources: ECGs, EMGs, EEGs, blood pressure signals, etc. Course integrates physiological knowledge with the information useful for physiologic investigation and medical diagnosis and processing. Biomedical signal characterization, time domain analysis techniques (transfer functions, convolution, auto- and cross-correlation), frequency domain (Fourier analysis), continuous and discrete signals, deterministic and stochastic signal analysis methods. Analog and digital filtering.
Recommended background: ECE 2311, ECE 2312, or equivalent.
This course will be offered in 2020-21, and in alternating years thereafter.

BME/ECE 4023. BIOMEDICAL INSTRUMENTATION DESIGN.
Cat. I
This course builds on the fundamental knowledge of instrumentation and sensors. Lectures cover the principles of designing, building and testing analog instruments to measure and process biomedical signals. The course is intended for students interested in the design and development of electronic bioinstrumentation. Emphasis is placed on developing the student's ability to design a simple medical device to perform real-time physiological measurements.
Recommended background: BME 3012, BME 3013, ECE 2010 or ECE 2019.

BME 4201. BIOMEDICAL IMAGING.
Cat. II
This course provides an understanding of fundamental principles of various biomedical imaging modalities as well as computational image analysis. Topics include: light microscopy, computed tomography, magnetic resonance imaging, computational image analysis, and review of computer vision theory and the relevant principles of physics. Course work uses examples from light microscopy, computed tomography, X-ray radiography, and magnetic resonance imaging. Familiarity with a high-level programming language is recommended.
This course will be offered in 2020-21, and in alternating years thereafter.

BME 4300. MQP CAPSTONE DESIGN.
Cat. I (1/6 unit)
This course guides students through the engineering design process during the first term of their MQP to aid them in fulfilling their capstone design requirement. The course focuses on developing a revised client statement based on the objectives, constraints, and functions of the design. Methods for concept generation, concept selection and development strategy will be covered. In addition, project planning tools, business plans, ethics, and design for manufacturability and sustainability will be covered.
Recommended background: Principles of engineering design such as BME 3300 or equivalent. Course should be taken concurrently with the MQP. Students who have taken BME 430X may not get credit for BME 4300. BME 4300 cannot be used to fulfill graduate degree requirements.

BME/ME 4504. BIOMECHANICS.
Cat. I
This course emphasizes the applications of mechanics to describe the material properties of living tissues. It is concerned with the description and measurements of these properties as related to their physiological functions. Emphasis on the interrelationship between biomechanics and physiology in medicine, surgery, body injury and prostheses.

Topics covered include: Review of basic mechanics, stress, strain, constitutive equations and the field equations, viscoelastic behavior, and models of material behavior. The measurement and characterization of properties of tendons, skin, muscles and bone. Biomechanics as related to body injury and the design of prosthetic devices.

Recommended background: Mechanics (ES 2501, ES 2502, ES 2503, ME 3501), Mathematics (MA 2051).

This course will be offered in 2019-20, and in alternating years thereafter.

BME/ME 4606. BIOFLUIDS.
Cat. II
This course emphasizes the applications of fluid mechanics to biological problems. The course concentrates primarily on the human circulatory and respiratory systems. Topics covered include: blood flow in the heart, arteries, veins and microcirculation and air flow in the lungs and airways. Mass transfer across the walls of these systems is also presented.

Recommended background: ME 3501 and fluid mechanics equivalent to ES 3004.

This course will be offered in 2020-21, and in alternating years thereafter.

BME 4701. CELL AND MOLECULAR BIOENGINEERING.
Cat. I
This course examines the principles of molecular and cell biology applied to the design of engineered molecules, cells and tissues. Topics will include the basic structural, chemical and physical properties of biomolecules (proteins, lipids, DNA and RNA), application of biomolecules to monitor and alter cellular processes in vitro and in vivo, and design considerations for engineering cell and molecular therapeutics. Case studies will be used to examine specific applications of molecular and cellular bioengineering technologies to treat disease and promote tissue repair and regeneration.

Recommended background: Cell biology (BB 2550). Additional coursework in molecular biology (BB 2950) and/or genetics (BB 2920) would be beneficial.

Students who earned credit for BME 37XX may not receive credit for BME 4701.

BME/ME 4814. BIOMATERIALS.
Cat. I
A course discusses various aspects pertaining to the selection, processing, testing (in vitro and in vivo) and performance of biomedical materials. The biocompatibility and surgical applicability of metallic, polymeric and ceramic implants and prosthetic devices are discussed. The physico-chemical interactions between the implant material and the physiological environment will be described. The use of biomaterials in maxillifacial, orthopedic, dental, ophthalmic and neuromuscular applications is presented.

Recommended background: BB 3130 or equivelant introduction to Human Anatomy, ES 2001 or equivelant introduction to Materials Science and Engineering.

BME 4828. BIOMATERIALS-TISSUE INTERACTIONS.
Cat. I
This course examines the principles of materials science and cell biology underlying the design of medical devices, artificial organs and scaffolds for tissue engineering. Molecular and cellular interactions with biomaterials are analyzed in terms of cellular processes such as matrix synthesis, degradation and contraction. Principles of wound healing and tissue remodeling are used to study biological responses to implanted materials and devices. Case studies will be analyzed to compare tissue responses to intact, bioresorbable and bioerodible biomaterials. Additionally, this course will examine criteria for restoring physiological function of tissue and organs and investigate strategies to design implants and prostheses based on control of biomaterial-tissue interactions.

Recommended background: BB 2550 or equivalent, ES 2001 or equivalent, PH 1110 or PH 1111.

BME 4831. DRUG DELIVERY.
Cat. I
The course examines fundamental composition, structure, property and performance relationships in classical and novel drug delivery systems as part of disease treatment strategies (i.e. cancer, organ damage). Physiological barriers to drug delivery and methods to overcome these barriers are analyze. The course will familiarize students with biomaterial-based drug delivery systems that have recently been developed. Topics include routes of drug administration, diffusion, Fick's law, pharmacokinetics/pharmacodynamics, drug modifications, materials for drug delivery (implantable, transdermal, injectable), antibody therapeutics, cells as drugs and drug delivery vehicles, and novel drug formulations and delivery systems.

Recommended background: Fundamental knowledge of biomaterials (e.g. BME 2811 or equivalent), multivariable calculus (e.g. MA 1024 or equivalent) and biological system function or cell function (e.g., BB 1035 or BB 2550 or equivalent)

BIOMEDICAL ENGINEERING LAB COURSES

BME 3012. BIOMEDICAL SENSORS LABORATORY.
Cat. I (1/6 unit)
This laboratory-based course is designed to develop hands-on experimental skills relevant to the selection and application of various sensors used to acquire biomedical signals.

Recommended background: BME 2210, ECE 2010, ECE 2019 or equivalent.

Students who have previously taken BME 3011 may not receive credit for this course.

BME 3013. BIOMEDICAL INSTRUMENTATION LABORATORY.
Cat. I (1/6 unit)
This laboratory-based course is designed to develop hands-on experimental skills relevant to the design and application of analog instrumentation commonly used to acquire biomedical signals.

Recommended background: BME 2210, ECE 2010, ECE 2019 or equivalent.

Students who have previously taken BME 3011 may not receive credit for this course.

BME 3014. SIGNAL PROCESSING LABORATORY.
Cat. I (1/6 unit)
This course is an introduction to the computational methods used to extract and analyze the signals produced by biomedical phenomena. The goal of this course is to familiarize the student with implementing the most common algorithmic approaches for data analysis used in biomedical engineering. Coursework will cover programming for topics such as peak detection, spectral analysis and the fast Fourier transform FFT method, auto-regression analysis, polynomial trend removal, and signal filtering methods.

Recommended background: BME 2211, CS 1004 or equivalent.

BME 3503. SKELETAL BIOMECHANICS LABORATORY.
Cat. I (1/6 unit)
This laboratory course will help students increase their knowledge of the mechanics of the musculoskeletal system. Students will gain understanding of the course materials and technical skills through the combined hands-on application of state-of-the-art biomechanical testing equipment and computer simulation modules towards solving authentic problems involving balance, strength, and movement.

Recommended background: Statics (ES 2501) and dynamics (ES 2503).

Students who have previously taken BME3504 may not receive credit for this course.

BME 3505. SOLID BIOMECHANICS LABORATORY: TECHNIQUES.
Cat. I (1/6 unit)
This laboratory-driven solid biomechanics course provides hands-on experience in characterizing the mechanical properties of biological tissues such as bone, tendons, ligaments, skin, and blood vessels and their synthetic analogs. Students gain an in-depth understanding of the course material by performing uniaxial tension and compression, bending, and torsion tests on hard and soft tissues using industry-standard testing equipment and completing mechanical and statistical analysis of the data.

Recommended background: A solid knowledge of mechanics of materials (ES2502) and material science (ES 2001). Students who have previously taken BME3504 may not receive credit for this course.

Some sections of this course may be offered as Writing Intensive (WI).

BME 3506. SOLID BIOMECHANICS LABORATORY: APPLICATIONS.
Cat. I (1/6 unit)
This laboratory-driven solid biomechanics course provides hands-on experience in characterizing the mechanical properties of biological tissues such as bone, tendons, ligaments, skin, and blood vessels and their synthetic analogs, in the context of an authentic challenge. Students gain an in-depth understanding of the course material from personal observations, measurements, and analysis of biological tissues and synthetic replacement/fixation materials using industry-standard testing equipment. A challenge-based laboratory project will be assigned which will require the students to determine and execute effective test methods at their own pace in a team setting and communicate their findings effectively.

Recommended background: Ability to independently perform tensile and bending tests using a uniaxial mechanical testing machine and to perform mechanical and statistical analysis of test data (BME3505). Students who have previously taken BME3504 may not receive credit for this course.

Some sections of this course may be offered as Writing Intensive (WI).

BME 3605. BIOTRANSPORT LABORATORY.
Cat. I (1/6 unit)
This laboratory-driven transport course provides hands-on experience in measuring heat, flow, and transport in biologically-relevant systems. Students gain an in-depth understanding of the course material from personal observations and measurements on model cardiovascular systems and connective tissues. Challenge-based laboratory projects will be assigned which will require the students to determine and execute effective test methods at their own pace in a team setting and communicate their findings effectively. Systems modeled may include blood vessels, stenotic vessels, and aneurysms. Connective tissues tested may include blood vessels and skin.

Recommended background: Basic Chemistry (CH 1010, CH 1020), Basic Physics (PH 1010), Material Science (ES 2001 or BME 2811), stress analysis (ES 2502 or BME 2502) and a knowledge of cell biology (BB 2550), or equivalent.

BME 3811. BIOMATERIALS LAB.
Cat. I (1/6 unit)
This laboratory-driven course provides hands-on experience in the design, fabrication and characterization of biomaterials for medical applications. Students will use synthetic and natural polymer materials to fabricate a scaffold for applications such as tissue engineering, wound healing or controlled drug delivery. A challenge-based laboratory project will be assigned which will require the students to design a biomaterial scaffold that meets specific design criteria, and quantitatively assess the properties of this scaffold to evaluate how well the criteria were met. Design criteria may include mechanical strength, biocompatibility, porosity, degradation rate, or release kinetics. Students will complete the project at their own pace in a team setting and communicate their findings effectively.

Recommended background: Basic chemistry (CH 1010 and CH 1020) and a knowledge of material science (ES 2001) or equivalent.

BME 3813. CELLULAR ENGINEERING LAB.
Cat. I (1/6 unit)
This laboratory-driven course provides hands-on experience in the application of bioengineering to control cellular processes. Students will be challenged to design an intervention to manipulate a specific cellular process (adhesion, proliferation, migration, differentiation) and use modern cellular and molecular biology tools to assess and refine their approach. Laboratory exercises will provide an overview of cell culture technique, microscopy and molecular probes, quantification of cell proliferation and migration, and assessment of cellular differentiation in the context of the assigned projects. Students will complete the project at their own pace in a team setting and communicate their findings effectively.

Recommended background: Basic chemistry (CH 1010 and CH 1020) and a solid knowledge of cell biology (BB 2550) or equivalent.

BUSINESS, ROBERT A. FOISIE SCHOOL OF

ACCOUNTING (ACC)

ACC 2101. MANAGEMENT ACCOUNTING.
Cat. II
This course is intended to familiarize the student with the wide variety of ways in which accounting data are used by management as a tool for the attainment of predetermined organizational objectives. The emphasis of the course is on the application of accounting data, rather than on its preparation, and particular attention is given to the use of financial data both in controlling day-to-day activities and planning future operations. Principal topics include: master budgets, cost analysis and classification systems, cost-volume-profit analysis, standard cost accounting and an introduction to capital budgeting.

Recommended background: BUS 2060.

This course will be offered in 2021-22, and in alternating years thereafter.

BUSINESS (BUS)

BUS 1010. LEADERSHIP PRACTICE.
Cat. I
Leadership is a critical role in any global, technological organization. This course explores how the concepts of creativity, entrepreneurial and critical thinking, emotional and self-awareness, passion, diversity, communication, and ethics inform and affect leadership practice. The course considers a variety of contemporary leadership challenges including how leaders work effectively across cultural, technological, and disciplinary boundaries, how leaders foster new ideas and bring them to fruition, how they communicate effectively and persuasively to diverse stakeholders, and how they make decisions that are both ethical and effective. The course is designed to 1) increase students' awareness of their own leadership styles, 2) examine the responsibilities of leadership, and 3) determine best practices in leadership.

BUS 1020. GLOBAL ENVIRONMENT OF BUSINESS DECISIONS.
Cat. I
The global nature of business is indisputable. This course introduces the students to the complexity of the global environment and adopts a multi-dimensional view (cultural, economic, social, legal, political, and technological) of world economy. It promotes understanding the global environment as integrative forces affecting the success or failure of today's businesses and fosters a global perspective. Topics may include an overview of the world economy, comparative advantage and international trade, cultural distance, FDI/globalization theory, outsourcing and global supply chain coordination, political and country risk, the global monetary system and currency risk, legal and ethical issues, and risk management.

BUS 2020. THE LEGAL ENVIRONMENT OF BUSINESS DECISIONS.
Cat. I
This course addresses the impact of law on business. The course covers fundamental areas of business law, such as torts, contracts, intellectual property, and legal forms of business organizations, and their effects on business decisions. Particular attention is paid to technology-based enterprises where global business issues intersect with law.

BUS 2060. FINANCIAL STATEMENTS FOR DECISION MAKING.
Cat. I
This course provides students with an understanding of the primary financial statements used for internal and external business decision-making in start-up firms and large corporations. It emphasizes underlying accounting concepts captured in financial statements, while highlighting the interdependence among these statements. The course will cover analytical techniques, such as ratio analyses and sensitivity analyses to assess the impact of changes in strategy and outcomes on efficiency and effectiveness measures. It also describes the various users of internal and external financial statements, and the potential conflicts between these various stakeholders.

BUS 2070. RISK ANALYSIS FOR DECISION MAKING.
Cat. I
Financial and operational risks are omnipresent in small entrepreneurial enterprises and in the corporate world. All firms, large and small, must be able to manage risk to create value. This course introduces students to enterprise risk and prepares them to act in the presence of risk. The course will sensitize students to two significant types of risk (namely, financial and operational risk), provide students with tools for assessing risk and minimizing risk exposure, and prepare students to take risk into account when making decisions as leaders, managers, and individuals.

BUS 2080. DATA ANALYSIS FOR DECISION MAKING.
Cat. I
This course builds upon students' understanding of statistics and introduces them to the concepts and methods for analyzing data to support business decision-making. Students will explore data sets using data mining and analytics techniques to create business intelligence, to be used for understanding and improving customers' experiences, supply chain operations, product management, etc. During the course, students will develop an understanding of the uses of business data analytics and associated models for business decision-making, forecasting, and obtaining and maintaining a competitive advantage. Students will learn a comprehensive set of advanced spreadsheet skills, including how to design, build, test, and use spreadsheets for analyzing business decisions.
Recommended background: Basic statistics, equivalent to that in MA 2611 and MA 2612.

BUS 3010. CREATING VALUE THROUGH INNOVATION.
Cat. I
This course focuses on the ways value can be created and captured through innovation. Focusing on the assessment of customers, organizational capabilities, and competition, students will consider a variety of different types of innovations and their associated ethical and financial value propositions. Students will learn analytic tools to successfully assess and commercialize technology, product, and service innovations in a variety of contexts.

BUS 3020. ACHIEVING EFFECTIVE OPERATIONS.
Cat. I
Operations are embedded in a constantly changing network of relationships with various stakeholders including customers and suppliers. Within the organization, scarce resources (including financial, human, and technological) need to be ethically allocated and aligned with strategic goals. This course focuses on process analysis, design, and implementation within the constraints of stakeholder networks and available resources.

BUS 4030. ACHIEVING STRATEGIC EFFECTIVENESS.
Cat. I
Every successful business has a strategy for how it provides value and earns profit within its particular industry. Focusing on the contexts of technology, innovation and entrepreneurship, this course develops analytic approaches for assessing the various aspects of strategy such as the competitive environment, the network of stakeholders, ethical implications, investor motivation, operational execution, and financial projections that are necessary to create a complete business plan.

BUS 4300. SENIOR SEMINAR.
Cat. 1
This course is designed for the senior student who wishes to acquire or strengthen important skills needed for organizational success. Among the subjects covered is power in organizations, what it is, and how to acquire and appropriately use it. Additionally, this course emphasizes presentation skills, organizational etiquette, cross-cultural communication, and the knowledge of current events. The student will be expected to be familiar with and use all forms of media information for both individual and group projects. The course may be counted as a 4000-level elective for BU, MGE, or MIS, or as a Free Elective for any student at WPI.
Recommended Background: Senior standing.

ENTREPRENEURSHIP (ETR)

ETR 1100. ENGINEERING INNOVATION AND ENTREPRENEURSHIP.
Cat. I
In the modern competitive and global world confronting today's engineers, innovation and entrepreneurship (I&E) are increasingly important perspectives for every engineering career. Individuals proficient in I&E are likely to possess unique competitive advantage over those who do not. This course develops the foundation for developing such proficiency by examining the functional roles of the business/commercial aspects of engineering disciplines as well as establishing a basis for innovative thinking. Specific cases where I&E has led to new products innovation and new enterprise development will supplement course materials.

ETR 2900. SOCIAL ENTREPRENEURSHIP.
Cat. I
This course will introduce students to the concept of social entrepreneurship and the ways in which social entrepreneurs are addressing complex social problems with their entrepreneurial ventures. Students will be exposed to the challenges and rewards of running a social enterprise. They will learn valuable business and entrepreneurial tools that can be applied to the design of sustainable social business models. Topics include social opportunity recognition and evaluation, business models in the social sector, social impact assessment, the double-bottom line, scalability of solutions, organizational forms and structures, and social venture financing.
Suggested background: Familiarity with concepts of creativity, innovation, entrepreneurial and critical thinking, ethics, cross-cultural relations, and social problems (BUS 1010, BUS 1020, BUS 2060 or equivalent).

ETR/ECON 2910. ECONOMICS AND ENTREPRENEURSHIP.
Cat. I
This course is designed to provide an introduction to economics, an introduction to entrepreneurship, and an understanding of the linkages between economics and entrepreneurship. Students will apply these concepts to the assessment of opportunities that might arise from participation in WPI projects. Students will engage in exploring how economics and entrepreneurship can inform opportunity assessment within an ambiguous and uncertain context. These decisions are always made with incomplete information and there is typically no single correct answer but rather multiple possible answers -- each with pluses and minuses.
Recommended background: None

ETR 3633. ENTREPRENEURIAL SELLING.
Cat. I
Selling is a major part of business life, but it is especially important for those who are launching a new venture. They need to sell their business plan to potential investors. Later they need to sell their product or service to a customer. Ultimately they need to create an organization that is focused on meeting customer and other stakeholder needs through effective selling disciplines. This course will examine the elements of the sales cycle in terms of preparation, market research, prospecting, objection handling, closing, techniques for motivating the sales professional and formulation of strategy for the successful selling transaction. As part of the course students will be required to prepare individual sales presentations, one to secure investment for a new venture and one to sell a product or service to a customer. Guest speakers may be used on topics such as sales coaching, inside sales management, and to deliver sales effectiveness training.

ETR 3915. ENTREPRENEURIAL BUSINESS MODELS.
Cat. I
This course is designed to foster an understanding of entrepreneurship in the context of innovation and the global economy. It also provides the theoretical and practical knowledge for the preparation of business models. The course includes opportunity identification, team formation, capital and other resource acquisition, exit strategies and other aspects of new venture creation.
Recommended Background: BUS 2020, BUS 2060, BUS 3010, BUS 3020 and OIE 2850.

ETR 4930. GROWING AND MANAGING NEW VENTURES.
Cat. I
One of the most troublesome aspects of entrepreneurship is running the business once it is started. This course focuses on techniques to grow the new venture and how to manage both the growth and operations. Considerable emphasis will be placed on expanding existing markets, finding new markets, anticipating the next generation of products, and managing cash flow.
Recommended background for this course consists of five of the following: ACC 2101, BUS 1010, BUS 1020, BUS 2020, BUS 2060, BUS 3010, BUS 3020, BUS 4030, ETR 3915, OIE 2850.

FINANCE (FIN)

FIN 1250. PERSONAL FINANCE.
Cat. I
This course is designed to help the student make well-informed judgments when faced with personal financial decisions. Such decisions are growing in number and complexity, and both individuals and families need a considerable degree of financial expertise in order to utilize optimally their limited incomes. Principal topics include: insurance (medical, life, automobile and disability), consumer credit, estate planning, taxation, personal investments (real estate, securities, etc.), social security legislation and personal financial planning.

FIN 3300. FINANCE, RISK ANALYTICS & TECHNOLOGY.
Cat. I
This course provides an in-depth overview of finance, methods in risk analytics, and the importance of financial technology in today's global and interconnected marketplace. In this course, students learn the most up-to-date methods and tools that are used globally within the financial services industry. Topics covered include portfolio formation based on personal and risk preferences, the formation and backtesting of trading strategies, fundamental and technical analysis, the mutual fund and hedge fund industries, and cryptocurrencies. These topics are explored using big data and risk analytics methods such as time series modeling, prediction models, volatility risk forecasting, and the identification and distinction between market-wide and industry-specific risks. Throughout the course, students will learn how to use Bloomberg to analyze data across market sectors to make financial decisions. This course is especially suited to those seeking careers where data analytics and information technologies play critical roles in finance or the management of risks. Topics covered in this course appear regularly in examinations required for professional certifications, such as the Chartered Financial Analyst (CFA) certification. The risk analytics portion of this course also covers topics that appear regularly in the financial mathematics examination by the Society of Actuaries (SOA).
Recommended Background: Introductory business and finance topics such as those found in BUS 2060.

MANAGEMENT INFORMATION SYSTEMS (MIS)

MIS 3720. BUSINESS DATA MANAGEMENT.
Cat. I
This course introduces students to the theory and practice of database management and the application of database software to implement business information systems that support managerial and operational decision making. Special topics covered include relational data models, query languages, normalization, locking, concurrency control and recovery. The course covers data administration and the design of data tables for computerized databases. Students will use a commercial database package to design and implement a small business database application.
Recommended background: CS 2119 or equivalent knowledge.

MIS 3787. BUSINESS APPLICATIONS OF MACHINE LEARNING.
Cat. I
This course offers a business focused data analytics introduction. Using cutting-edge tools and approaches to the analysis of data through supervised machine learning, the course teaches how to utilize "big data" for effective decision-making. The course creates data analytics skills through hands-on exposure to data and analytic techniques embedded in Automated Machine Learning tools. Application areas covered include Marketing (pricing and marketing of luxury shoes), Supply Chain (predicting parts backorders), Finance (predicting safe loans), Talent Management (predicting and explaining attrition), Service Delivery (predicting hospital readmissions), as well as student-centric topics (college grades and starting salaries). This course provides foundations required to successfully apply the machine learning approaches to many of the most common business problems.

MIS 4084. BUSINESS INTELLIGENCE.
Cat. I
This course provides an introduction to the technologies and techniques for organizing, analyzing, visualizing, and presenting data about business operations in a way that creates business value, and prepares students to be knowledgeable producers and consumers of business intelligence. During the course, students will study a variety of business decisions that can be improved by analyzing large volumes of data about customers, sales, operations, and business performance. Students will employ commercially available business intelligence software to organize, summarize, visualize, and analyze data sets and make recommendations to decision makers based on the results. The course explores the technical challenges of conducting analytics on various forms of data including social media data and the managerial challenges of creating value from business intelligence expertise deployed in organizations. The course includes business cases, in-class discussion, hands-on analyses of business data, and methods for presenting results to decision makers. It is designed for any student interested in analyzing data to support business decision-making, including students whose primary focus is Management Information Systems, Marketing, Operations and Industrial Engineering, Business, Management Engineering, Data Science, or Computer Science.
Recommended background: Previous knowledge in data management, such as that provided by MIS 3720 Business Data Management or CS 3431 Database Systems I.

MIS 4720. SYSTEMS ANALYSIS AND DESIGN.
Cat. I
This course integrates students' background in MIS in a one-term project focusing on development of creative solutions to open-ended business and manufacturing problems. The project will utilize systems analysis and design tools such as systems development life cycle, feasibility study, cost-benefit analysis, structured analysis and design. Students will acquire the skills necessary to analyze, develop, implement, and document real-life information systems. Students must be able to organize themselves and the project to complete their work within a seven week term. It is recommended that MIS majors take this course in preparation for their MQP.
Recommended background: MIS 3720.

MIS 4741. USER EXPERIENCE AND DESIGN.
Cat. I
This course focuses on the newest developments in the field of user experience (UX) (e.g., the use of physiological measures such as eye tracking in UX design) and provides an introduction to various methods used in cutting-edge research laboratories to study user experience. Both theoretical concepts and practical skills with appropriate development tools will be addressed within the scope of the class through hands-on projects and assignments. Students will develop a plan to innovate with user experience and will implement a simple prototype of their plan.
Recommended background: BUS 3010, CS 2102 (or CS 2103) or ability to program in a higher level programming language.

MIS 4781. INFORMATION SYSTEMS AND TECHNOLOGY POLICY AND STRATEGY.
Cat. II
A successful MIS manager must keep up with the fast-paced changes in technology, apply technology when appropriate, and understand the implications technology has on employees and an organization as a whole. S/he must understand both the internal (e.g., political and organizational culture) and external (e.g., laws, global concerns, and cultural issues) environments. The core MIS capabilities of business and information technology (IT) vision, design of IT architecture, and IT service delivery also need to be understood by effective MIS managers.
Recommended background: BUS 3010, MIS 3720 and MIS 4720
This course will be offered in 2021-22, and in alternating years thereafter.

MARKETING (MKT)

MKT 3640. MANAGEMENT OF PROCESS AND PRODUCT INNOVATION.
Cat. I
This course is based on the hypothesis that high performance firms depend on a sustainable pattern of new and innovative processes and products. Successful companies are examined in regard to their strategies for innovation and technology transfer. Technology alliances among industry, universities, and government are considered in order to increase the leverage of the individual firm. Benchmarking and commercialization from research to actualization is discussed through cases and examples.
Recommended background: BUS 2070 or OIE 2850.

MKT 3650. CONSUMER BEHAVIOR.
Cat. I
Knowing how to manage and interact with customers is a key component for business success. Today, customer needs are continuously evolving as well as how products and services are purchased and consumed. Understanding consumer behavior concepts allows firms to investigate consumption habits and make better informed managerial decisions. The goal of this course is to provide an introduction to various theories and dimensions of consumer behavior, such as the consumer decision-making process, the influence of attitude towards the product, brand, and/or firm, and the impact of culture and subculture. Students will be exposed to how these concepts are linked and applied to marketing, to our roles as consumers, and to everyday decisions.

OPERATIONS AND INDUSTRIAL ENGINEERING (OIE)

OIE 2081. INTRODUCTION TO PRESCRIPTIVE ANALYTICS
Cat. I
This course provides an introduction to prescriptive analytics, which involves the application of mathematical and computational sciences, such as linear optimization and simulation, to recommend optimal courses of action for decision making. The course will feature decision problems arising from a variety of contexts such as capacity management, finance, healthcare, humanitarian relief, inventory management, production planning, staffing, and supply chain. The emphasis of the course is the application of such techniques to recommend a best strategy or course of action for the particular context.
Recommended background: Basic statistics, equivalent to that in MA 2611 and MA 2612.

OIE 2850. ENGINEERING ECONOMICS.
Cat. I
To aid all engineering students in understanding economics and business constraints on engineering decision making. Topics include evaluation of alternative; the six time-value-of-money factors; present worth, annual cash flow and rate-of-return analysis; incremental analysis; depreciation and income taxes; replacement analysis; inflation; handling probabilistic events; public economy; break-even and minimum cost points; and foreign exchange.

OIE 3405. WORK SYSTEMS AND FACILITIES PLANNING.
Cat. I
This course covers the fundamentals of developing efficient layouts for production and service facilities. Methods analysis, work measurement, material handling and material flow analysis are also covered. Mathematical models and computer tools are used to assist decision-making.
Recommended background: BUS 3020 and OIE 2081.

OIE 3410. MATERIALS MANAGEMENT IN SUPPLY CHAINS.
Cat. I
This course in an introduction to the planning and controlling the material flow into, through, and out of an organization. It explains fundamental relationships among the activities that occur in the supply chain from suppliers to customers. In particular, the course addresses types of manufacturing systems, demand management and forecasting, master production scheduling, materials requirements planning, capacity management, inventory management, distribution resource planning, JIT and lean principles, and other current topics that are pertinent to managing the material flow of supply chains.
Recommended background: MA 1020, MA 1021, MA 2611 and BUS 3020.

OIE 3420. QUALITY PLANNING, DESIGN AND CONTROL.
Cat. I
This course provides students with the analytical and management tools necessary to solve manufacturing and service quality problems. Topics include customer needs and quality, quality and cost relationships, process capability analysis, statistical process control, control charts for variables and attributes, design of experiments, and other Six Sigma problem solving methodology.
Recommended background: BUS 3020 and MA 2612 or consent of the instructor.

OIE 3460. SIMULATION MODELING AND ANALYSIS.
Cat. I
This course covers the application of simulation to a variety of managerial problems with examples from operations management, industrial engineering and manufacturing engineering. It introduces the student to the concepts of computer simulation, with an emphasis on the design of a simulation experiment and statistical interpretation of its results. It will discuss simulation of queueing models, inventory and industrial dynamics, and gaming situations. The role and use of computers for the execution of simulations will also be highlighted. A commercial simulation language such as Arena will be used to solve problems from the manufacturing and service industries.
Recommended background: CS 1004 and MA 2612.

OIE 3510. STOCHASTIC MODELS.
Cat. I
This is an introductory course in probabilistic models and decision-making under risk, with applications to engineering and management decision making. The course first covers quantitative methods for assessing and evaluating risks and how they are used in decision making. Decision making under risk is examined across a wide set of management and engineering problems. The course then introduces a set of probabilistic models commonly used in decision making and operations improvement; specifically, emphasis is placed on Markov chains, Poisson processes, and queuing theory, and their applications in manufacturing and service systems are illustrated.
Recommended background: Knowledge of calculus and introductory probability and statistics.

OIE 3600. SCRIPTING FOR PROCESS AND PRODUCTIVITY IMPROVEMENT.
Cat. I
This course will train students to think critically about the effective and efficient use of computational tools to enhance everyday organizational performance. Students will learn how to create value through productivity tools that will likely include advanced spreadsheet functionality, regular expressions, macros, and scripting. The course will make use of software including Microsoft Excel with Visual Basic for Applications, Python, and advanced text editors, applied to a variety of domains, to improve students' ability to automate processes and productivity.
Students can receive credits for both OIE 3600 and either CS 2119 or CS 2102 or CS 2103. For IE majors, if one of the CS courses previously listed is used as a required programming course, then OIE 3600 can be used as an IE elective.
Recommended background: some previous exposure to analytical problem solving as found in OIE 2081 or MA 2210.

OIE 4410. CASE STUDIES IN INDUSTRIAL ENGINEERING.
Cat. I
A number of in-depth case studies in operations and industrial engineering are analyzed. The cases will cover both manufacturing and service systems ranging from production system design to operations planning and control.
Recommended background: BUS 3020, OIE 2081, OIE 3410, and OIE 3510.

OIE 4420. PRACTICAL OPTIMIZATION: METHODS AND APPLICATIONS.
Cat. I
This course covers the use of practical computational methods to solve constrained optimization problems from industry. Optimization theory and algorithms related to linear and integer programming will be discussed, with primary emphasis placed upon computationally solving applications in the industrial, operational, manufacturing, and service sectors. Both proprietary and open-source optimization software will be used, including spreadsheet solvers

(e.g., Excel Solver, OpenSolver), industrial-strength optimization packages (e.g., CPLEX, GUROBI), and other interfaces (e.g., MATLAB, AMPL). Students will be expected to model problems and interpret their results; where applicable, sensitivity analysis, duality and additional techniques will be utilized to gain managerial insight from developed models and solutions. Cases from industries such as health care, supply chain management, financial services and analytics will be used for illustrations, discussions, and exercises.

Recommended background: Familiarity with some basic linear programming OIE 2081, MA 2210, MA 3231, or equivalent.

OIE 4460. GLOBAL PLANNING AND LOGISTICS.
Cat. I
This case-based course will examine methods and strategies for managing and controlling material movement, with particular emphasis on international operations, from the purchase of production materials to the control of work in process to the distribution of the finished product. Strategies that will be discussed include the design of international distribution networks, the use of third-party logistics providers, and the creation of links between logistic systems and marketing to create competitive advantage. The course will also explore tactical issues that must be managed to pursue a logistics strategy successfully, including choices regarding means of transportation, packaging, and inventory policies. Underlying themes of the course will be the use of information technologies (such as electronic data interchange and bar coding) and mathematical models to support logistics decision-making.

Recommended background: BUS 3020 and one of the following: BUS 2070 or OIE 2850 or consent of the professor.

ORGANIZATIONAL BEHAVIOR AND CHANGE (OBC)

OBC 3354. ORGANIZATIONAL BEHAVIOR AND CHANGE.
Cat. I
This course focuses on the basic knowledge and processes required of managers to understand behavior in organizations and to apply this knowledge to organizational change. Topics include communication and trust, power and leadership, group and intergroup processes, conflict and conflict management, and work and organizational design. Students apply their knowledge of organizational behavior to the analysis, implementation, and leadership of organizational change. Lectures, video presentations, case studies, group discussions and mini-projects are employed to introduce and illustrate the basic elements of organizational behavior and change.

Recommended background: None.

OBC 4367. LEADERSHIP, ETHICS, AND SOCIAL RESPONSIBILITY.
Cat. I
This upper-level course invites students to consider the importance of ethics, corporate governance, and corporate social responsibility for leading global enterprises effectively. Students will be asked to reflect on their own leadership styles and to engage the complex, ethical dimensions of leadership in modern organizations. The course will engage students using lecture, video presentations, case studies, guest speakers, fieldwork, and mini-projects.

Recommended background: None.

CHEMICAL ENGINEERING

NOTE: Courses listed in previous catalogs with “CM” as the prefix and the same course number as below are considered to be the SAME COURSE.

CHE 1011. INTRODUCTION TO CHEMICAL ENGINEERING.
Cat. I
This course provides an introduction to the broad and vital discipline of chemical engineering including conventional and developing chemical technologies. An introduction is provided to the first principles of chemical engineering, as well as environmental, health, safety and ethical issues in chemical engineering practice. An overview is provided of the chemical engineering profession, career choices, the course of study, and a survey of the chemical industry, e.g., polymer, pharmaceutical, food processing, microelectronic, electrochemical, biotechnology, process control, energy, and petroleum refining. Course activities include guest speakers and plant trips.

Recommended for first-year students with a basic knowledge of chemistry.

CHE 2011. CHEMICAL ENGINEERING FUNDAMENTALS.
Cat. I
This first course in chemical engineering is designed to give students the ability to use techniques and solve problems of interest to chemical engineers. Students will learn fundamental material by completing analysis, design, and/or laboratory projects. Topics covered include: material balances and stoichiometry, pressure, volume, and temperature behavior of pure fluids, 1st law of thermodynamics, vapor-liquid equilibria with ideal thermodynamics, and staged separation processes.

Recommended background: Elementary college chemistry and calculus.

Students may not receive credit towards CHE distribution requirements for both CHE 2011 and CM 2001.

CHE 2012. ELEMENTARY CHEMICAL PROCESSES.
Cat. I
This course aims to build a strong foundation in analysis of chemical processes via a project-based approach. Topics covered include analysis and design of stagewise separation processes such as distillation, 1st and 2nd law (of thermodynamics) analysis of power and refrigeration cycles, and application of material and energy balances in industrial chemical processes, including those with recycle and non-ideal systems.

Recommended background: Elementary college chemistry and calculus and some familiarity with the topics listed in CHE 2011.

Students may not receive credit towards CHE distribution requirements for both CHE 2012 and ES 3000.

CHE 2013. APPLIED CHEMICAL ENGINEERING THERMODYNAMICS.
Cat. I
This course uses a project-based approach to build confidence and competence in the use of chemical engineering thermodynamics for the analysis and design of chemical processes. Topics covered include extractive separation systems, solution thermodynamics and nonreacting multicomponent mixtures, phase equilibria and property changes on mixing.

Recommended background: Elementary college chemistry and calculus and some familiarity with the topics listed in CHE 2011 and CHE 2012.

Students may not receive credit towards CHE distribution requirements for both CHE 2013 and CM 2102.

CHE 2014. ADVANCED CHEMICAL PROCESSES.
Cat. I
This course builds on prior work in material and energy balances, chemical engineering thermodynamics, and stagewise separation processes to facilitate student mastery and design of more complex processes. Topics covered include chemical reaction equilibria, material and energy balances for non-steady state systems, combined material and energy balances, humidification, and batch distillation.

Recommended background: Elementary college chemistry and calculus and some familiarity with the topics listed in CHE 2011, CHE 2012, and CHE 2013.

Students may not receive credit towards CHE distribution requirements for both CHE 2014 and CM 2002.

Some sections of this course may be offered as Writing Intensive (WI).

CHE/ME 2301, NANOBIOTECHNOLOGY LABORATORY EXPERIENCE.
Cat. II
The current developments and experimental skills in nanoscale bioscience and biotechnology will be introduced. Experimental skills such as nanomaterials synthesis, electron microscopy and introductory biotechnology techniques are presented. This course will provide students training in laboratory technique and data handling.

Recommended background: CH 1010 or equivalent.

This course will be offered in 2020-21, and in alternating years thereafter.

CHE 3201. KINETICS AND REACTOR DESIGN.
Cat. I
Techniques for experimentally determining rate laws for simple and complex chemical reactions, the mechanisms and theories of chemical reactions, the function of catalysts, and the design of isothermal, adiabatic, batch and flow reactors. The course is intended to provide chemists and chemical engineers with the conceptual base needed to study reactions and perform in the design and analysis of reactors.

Recommended background: differential equations, thermodynamics and some organic chemistry.

CHE 3301. INTRODUCTION TO BIOLOGICAL ENGINEERING.
Cat. II
This course is an introduction to the chemical engineering principles involved in modern applications of biological engineering. Topics may include: an introduction to biology, biochemistry, physiology, and genomics; biological process engineering including fermentation, mammalian cell culture, biocatalysis, and downstream bioseparations; drug discovery, development, and delivery; environmental biotechnology; and chemical engineering aspects of biomedical devices.

Recommended background: material and energy balances, thermodynamics, organic chemistry, and differential equations.

This course will be offered in 2019-20, and in alternating years thereafter.

CHE 3501. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING.
Cat. I
The consolidation of the methods of mathematics into a form that can be used for setting up and solving chemical engineering problems. Mathematical formulation of problems corresponding to specific physical situations such as momentum, energy and mass transfer, and chemical reactions. Analytical and numerical techniques for handling the resulting ordinary and partial differential equations and finite difference equations.

Recommended background: ordinary differential equations, partial derivatives and vectors, momentum heat and mass transfer.

CHE 3702. ENERGY CHALLENGES IN THE 21ST CENTURY.
Cat. II
The goal of this course is to prepare students for future work in energy-related fields by providing an overview of the challenges related to energy production. Students will study several major energy systems. The details of such energy systems will be examined using engineering principles, particularly focusing on relevant chemical processes. For example, the details and processes of a typical power plant or a refinery will be examined. Students will also become familiar with environmental and economic issues related to energy production. Topics to be covered may include: fossil fuels, the hydrogen economy, biofuels, nuclear energy, fuel cells, batteries, and the electricity grid.

Recommended background: knowledge of chemistry (CH 1010, 1020, 1030), differential and integral calculus, and chemical processes (CHE 2011).

Students may not receive credit for both CHE 3702 and CHE 320X.

This course will be offered in 2019-20, and in alternating years thereafter.

CHE 3722. BIOENERGY.
Cat. II
The primary goal of this course is to provide students the necessary understanding and tools to evaluate biochemical and thermochemical biofuel production technologies. The secondary goals include developing understanding of 1) fuel properties, 2) biomass resources, 3) basic enzyme kinetics, 4) biochemical reactor design, 5) the corn ethanol process, 6) challenges to cellulosic ethanol, 7) biomass gasification reactions and thermochemistry, 8) gasification reactor design, and 9) techno economic concepts of biofuel processes.
Recommended background: Knowledge of chemistry (CH 1010, 1020, and 1030 or equivalent), differential and integral calculus and differential equations (MA 1021-1024 and 2051 or equivalent), and chemical processing (CHE 2011 or equivalent).
Students may not receive credit for both CHE 372X and CHE 3722.

This course will be offered in 2020-21, and in alternating years thereafter.

CHE/CE 4063. TRANSPORT & TRANSFORMATIONS IN THE ENVIRONMENT.
Cat. II
In this course, students will learn to make quantitative relationships between human activities and the effects on water, soil, and air in the environment. Students will learn the scientific and engineering principles that are needed to understand how contaminants enter and move in the environment, how compounds react in the environment, how to predict their concentrations in the environment, and how to develop solutions to environmental problems.

Topics to be covered may include water quality engineering (including microbial interactions), air quality engineering, and hazardous waste management.

Recommended Background: familiarity with transport phenomena, such as in ES 3004 (Fluid Mechanics) and ES 3002 (Mass Transfer), and familiarity with reaction kinetics and reactor design, such as through CHE 3201 (Kinetics and Reactor Design). Background such as CE 3059 (Environmental Engineering), CE 3060 (Water Treatment), or CE3061 (Wastewater Treatment) is suggested.

This course will be offered in 2020-21, and in alternating years thereafter.

CHE 4401. UNIT OPERATIONS OF CHEMICAL ENGINEERING I.
Cat. I
Laboratory-application of fundamental theories to practical chemical engineering operations. Emphasis is on building the student's understanding and ability to approach the problems of design and operations of large scale chemical processing equipment.

The course is a combination of lectures and laboratory projects in the area of unit operations. Laboratory projects include experiments in fluid-flow phenomena through various media such as: friction in conduits, filtration, pressure drop in packed towers, fluidization of solids, and spray drying.

Students are expected to carry out the planning and execution of experimental work as well as the analysis and reporting of experimental results in both written and oral format.

Recommended background: knowledge of chemistry, mathematics and engineering principles.

CHE 4402. UNIT OPERATIONS OF CHEMICAL ENGINEERING II.
Cat. I
Overall format and procedure are essentially the same as in Unit Operations of Chemical Engineering I.

Laboratory projects include experiments in heat and mass transfer such as: heat transfer in two heaters and a cooler, climbing film evaporation, multiple effect evaporation, absorption, extraction, distillation and rotary drying of solids.

Recommended backgound: familiarity with techniques and procedures emphasized in CHE 4401.

CHE 4403. CHEMICAL ENGINEERING DESIGN.
Cat. I
Design of equipment, systems and plants; discussion of factors important in chemical plant design such as: economics, cost estimation, profitability, process selection, materials of construction, process control, plant location and safety. Introduction to optimization and computer-aided design. Principles are illustrated with short industrial-type problems.

Recommended background: thermodynamics; heat, mass and momentum transfer; inorganic and organic chemistry; chemical kinetics and reactor design.

CHE 4404. CHEMICAL PLANT DESIGN PROJECT.
Cat. I
Application of Chemical Engineering design principles to the design of a major chemical plant. Students work in groups to produce a preliminary practical process flowsheet, equipment and plant design, and economic analysis.

Recommended background: familiarity with techniques and procedures emphasized in CHE 4403.

CHE 4405. CHEMICAL PROCESS DYNAMICS AND CONTROL LABORATORY.
Cat. I
This course is intended to provide laboratory application of fundamental principles of chemical process dynamics and feedback control. This includes open-loop dynamics of typical chemical engineering processes such as distillation, fluid flow, chemical reactors and heated stirred tanks. Closed-loop experiments will involve control loop design, controller tuning, multivariable, and computer control.

Students will be required to design and execute their own experiments based on supplied objectives. Analysis and presentation of the results will be done through oral and written reports.

Recommended background: knowledge of fluid flow and heat transfer, mathematics and chemical engineering principles.

CHE 4410. CHEMICAL PROCESS SAFETY DESIGN.
Cat. II
Application of chemical engineering design principles to the design of the process safety and environmental controls of a major chemical plant. Students work in groups to produce a preliminary practical flowsheet, equipment design and controls, and economic analysis, all associated with chemical process safety components within a plant. The course will also include an introduction to modeling of off-site impacts.

Recommended background: familiarity with techniques and procedures of chemical engineering design (CHE 4403), working knowledge of thermodynamics, heat, mass and momentum transfer, inorganic and organic chemistry, chemical kinetics and reactor design.

This course meets the requirements for a core course and a Capstone Design course in chemical engineering. Students may not receive core credit for both CHE 4404 and CHE 4410.

Graduate Chemical Engineering Courses of Interest to Undergraduates

CHE 504. MATHEMATICS ANALYSIS IN CHEMICAL ENGINEERING.
Methods of mathematical analysis selected from such topics as vector analysis, matrices, complex variables, Eigenvalue problems, Fourier analysis, Fourier transforms, Laplace transformation, solution of ordinary and partial differential equations, integral equations, calculus of variations, perturbation and asymptotic methods and numerical analysis. Emphasis on application to the solution of chemical engineering problems.

CHE 506. KINETICS AND CATALYSIS.
Theories of reaction kinetics and heterogeneous catalysis are developed for both simple and complex reactions. The kinetics and mechanisms of both catalyzed and uncatalyzed reactions are explored, as well as the effects of bulk and pore diffusion. Techniques for experimentation, reaction data treatment, and catalyst preparation and characterization are related to developing a sound approach to studying a chemical reaction.

CHE 507. CHEMICAL REACTOR DESIGN.
A review of the design of ideal reactors. Main course topics include: deviations from ideal reactor behavior; transport effects in reacting systems; steady state multiplicity and stability analysis; optimization of reactors; analysis of heterogeneous reactors.

CHE 508. CATALYSIS AND SURFACE SCIENCE OF MATERIALS.
The major factors which distinguished catalytic processes for chemicals and fuels from one another are the structure and composition of the materials used as catalysts.

This course examines the detailed structures and reactivities of solid catalysts like zeolites, solid state inorganics, supported metals and metal-support interactions, carbon catalysts, anchored catalysts and others. Several important spectroscopic techniques used in surface science such as X-ray photoelectron spectroscopy (ESCA), electron microprobe, AUGER, scanning electron microscopy, EXAFS, Mossbauer, Fourier-transform infrared, enhanced laser Raman spectroscopy and photoacoustics spectroscopy will be described for characterization of the catalytic surfaces.

The relationship between the structures and reactivities of important catalysts used in hydrocarbon oxidation and functionalization and syngas reactions will be examined to rationalize how they accomplish specific catalytic transformations.

CHE 510. DYNAMICS OF PARTICULATE SYSTEMS.
Systems of discrete particles which grow in size or some other characteristic variable (e.g., age, molecular weight, etc.) are analyzed. Both reaction engineering and population balance analyses are introduced for batch and continuous systems. Steady state and transient system dynamics are explored.

Depending on class interest, specific topics may include: crystallization, latex synthesis, polymer molecular weight distribution, fermentation/ecological systems and gas-solid systems.

CHE 521. BIOCHEMICAL ENGINEERING.
The course emphasizes the basic concepts of biological systems which are relevant to study by chemical engineers. Topics covered include ligand binding and membrane transport processes; growth kinetics of microorganisms; kinetics of interacting multiple populations; biological reactor design and analysis; soluble and immobilized enzyme kinetics; optimization and control of fermentation; and biological product recovery and separation.

CHE 531. FUEL CELL TECHNOLOGY.
The course provides an overview of the various types of fuel cells followed by a detailed discussion of the proton-exchange membrane (PEM) fuel cell fundamentals: thermodynamics relations including cell equilibrium, standard potentials, and Nernst equation; transport and adsorption in proton-exchange membranes and supported liquid electrolytes; transport in gas-diffusion electrodes; kinetics and catalysis of electrocatalytic reactions including kinetics of elementary reactions, the Butler-Volmer equation, reaction routes and mechanisms; kinetics of overall anode and cathode reactions for hydrogen and direct methanol fuel cells; and overall design and performance characteristics of PEM fuel cells.

CHE/CH 554. MOLECULAR MODELING.
This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical applications, for researchers who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a background at the introductory level in quantum mechanics is highly desirable. Methods to be explored include density functional theory, ab initio methods, semiempirical molecular orbital theory, and visualization software for the graphical display of molecules.

CHE 561. ADVANCED THERMODYNAMICS.
An examination of the fundamental concepts of classical thermodynamics and presentation of existence theorems for the thermodynamic properties with study of relations among them. The inequality of Clausius as a criterion for equilibrium in both chemical and physical systems. Examination of thermodynamic equilibrium for a variety of restraining conditions. Applications to fluid mechanics, process systems and chemical systems. Computation of complex equilibria.

CHE 571. INTERMEDIATE TRANSPORT PHENOMENA.
Mass, momentum and energy transport; analytic and approximate solutions of the equations of change. Special flow problems such as creeping, potential and laminar boundary-layer flows. Heat and mass transfer in multi-component systems. Estimation of heat and mass transfer rates. Transport with chemical reaction.

CHE 573. SEPARATION PROCESSES.
Thermodynamics of equilibrium separation processes such as distillation, absorption, adsorption and extraction. Multi-staged separations. Principles and processes of some of the less common separations.

CHE 574. FLUID MECHANICS.
Advanced treatment of fluid kinematics and dynamics. Stress and strain rate analysis using vectors and tensors as tools. Incompressible and compressible, one-dimensional flows in channels, ducts and nozzles. Nonviscous and viscous flow fields. Boundary layers and turbulence. Flow through porous media such as fixed and fluidized beds. Two-phase flows with drops, bubbles and/or boiling. Introduction to non-Newtonian flows.

CHE 580. SPECIAL TOPICS.
This course will focus on various topics of current interest related to faculty research experience.

CHEMISTRY AND BIOCHEMISTRY

GENERAL CHEMISTRY SEQUENCE

The general chemistry sequence, CH 1010—1040, is a unified sequence of courses in which areas of major importance in chemistry are discussed in depth from both the empirical and theoretical viewpoints. Each of the four courses develops a theme, or core idea, of chemistry. The sequence is designed for biology, science and engineering majors.

The format of each course includes four 1-hour classroom meetings and one 3-hour laboratory meeting per week. For reasons of safety, contact lenses may not be worn in the chemical laboratories. Prescription glasses meeting the ANSI standard Z87.1 will be accepted as affording adequate eye protection in the laboratory. Otherwise, goggles meeting these standards must be worn at all times.

CH 1010. CHEMICAL PROPERTIES, BONDING, AND FORCES.
Cat. I
The CH 1010 course is an introduction to chemistry using the fundamental structures of atoms as a starting point. Emphasis is placed on discussing how all properties of matter as well as bonding mechanisms arise from atomic structure. Lewis structures and molecular orbitals are used to understand bonding, and the intermolecular forces present in chemicals systems are used as a prelude to reactivity patterns covered in future courses.

CH 1020. CHEMICAL REACTIONS.
Cat. I
Bonding theories introduced earlier in the sequence are applied to chemical reactions, including reduction/oxidation reactions, to demonstrate patterns in reactivity. Solution thermodynamics, concentration scales, and colligative properties are discussed in the context of balanced chemical reactions both in aqueous solution and in the gas phase.

Recommended background: Properties of matter, basic bonding theory, Lewis structures and molecular orbitals, intermolecular forces. See CH 1010.

CH 1030. KINETICS, EQUILIBRIUM AND THERMODYNAMICS.
Cat. I
This course will examine the dynamic nature of solutions at the molecular level, and will develop an understanding of the mathematical aspects of molecular dynamics and equilibrium. Reaction kinetics will be outlined in detail leading into exploration of various fundamentals and examples of equilibrium processes in the gas phase as well as in solution, including acid-base chemistry and precipitation. Principles of thermodynamics will be introduced (entropy, free energy), and relationships with equilibrium will be explored. Case studies in current topics will be emphasized throughout the course.

Recommended background: Properties of matter, basic bonding theory, Lewis structures and molecular orbitals, intermolecular forces. Redox reactions, solution thermodynamics, colligative properties, balancing of chemical reactions. See CH 1010 and CH 1020.

CH 1040. SPECTROSCOPY IN ORGANIC AND POLYMER CHEMISTRY.
Cat. I
We will examine the nature of molecular motions and their interaction with electromagnetic radiation, which provides us with all of our structural information about molecules. In addition, students will be introduced to the fundamentals of mass spectrometry and electrochemistry. The concepts of these techniques will be discussed in the context of structural organic chemistry and polymer characterization

Recommended background: Properties of matter, basic bonding theory, Lewis structures and molecular orbitals, intermolecular forces. Redox reactions, solution thermodynamics, colligative properties, balancing of chemical reactions. Reaction kinetics, equilibrium processes, acid-base chemistry and principles of thermodynamics (entropy, free energy). See CH 1010, CH 1020 and CH 1030.

ORGANIC CHEMISTRY COURSES

CH 2310. ORGANIC CHEMISTRY I.
Cat. I
A systematic survey of the major reaction types and functional groups in organic chemistry. The course will provide a representative collection of characteristic reactions and transformations of a variety of types of organic molecules. Most of the examples will be drawn from aliphatic chemistry. Some theoretical models will be introduced with a view toward establishing a general overview of the material.

The course is intended for chemists, chemical engineers, pre-medical students and all those interested in the biosciences. A familiarity with the material presented in the general chemistry courses is assumed.

CH 2320. ORGANIC CHEMISTRY II.
Cat. I
Modern theories of aromaticity, including a general assessment of delocalized bonding. The chemistry of some significant functional groups not surveyed in Organic Chemistry I, and the meaning of acidity and basicity in organic chemistry, will be more fully explored. The course will provide an introduction to the systematic synthesis of polyfunctional organic compounds.

Recommended background: CH 2310. The course is intended for chemists, chemical engineers and bio-science majors.

CH 2330. ORGANIC CHEMISTRY III.
Cat. I
This course fully explores three most important analytical methods in organic chemistry: infrared spectroscopy, mass spectrometry, and nuclear magnetic resonance spectroscopy. It will continue the coverage of aromatic chemistry. New topics to be introduced include structures, properties, and reactivities of aldehydes and ketones, carboxylic acids and their derivatives, amines, and the interaction among polyfunctional compounds. It reinforces the retrosynthetic analysis and multistep synthesis of organic compounds and revisits reaction mechanisms and stereochemistry of all the new functional groups studied.

Recommended background: CH 2310 and CH 2320. The course is intended for biochemists, chemists, chemical engineers and bioscience majors.

CH 2360. ORGANIC LABORATORY.
Cat. I
Laboratory experience in standard methods for the preparation and purification of organic compounds. The course will provide sufficient training in laboratory technique so that no previous laboratory experience beyond that of general chemistry is required. This course may be taken concurrently or following lecture courses in organic chemistry. Recommended for pre-medical students and students majoring in disciplines outside of chemistry and biochemistry that desire laboratory experience in basic methods of organic synthesis.

Recommended background: Fundamentals of chemistry, basic chemistry laboratory techniques (e.g., basic synthesis, spectral analysis and chemical separation skills).

CH 3310. ADVANCED ORGANIC CHEMISTRY.
Cat. II
This course will review and further develop concepts introduced in CH 2310, CH 2320, and CH 2330. These concepts will include oxidation states of organic compounds, acidity and basicity, and stereochemistry and conformational analysis. Chemical reactivity will be emphasized and will include functional group interconversion and ionic and free radical carbon-carbon bond formation.

Recommended background: CH 2310, CH 2320, and CH 2330. This course is intended for students planning to take advanced courses in organic and/or medicinal chemistry and for chemists, biochemists, chemical engineers, and bio-science majors who desire a stronger background in organic chemistry.

This course will be offered in 2020-21, and in alternating years thereafter.

EXPERIMENTAL CHEMISTRY SEQUENCE

The following four courses provide a full-year laboratory program. The purpose of this sequence is to train students in the most essential laboratory techniques, procedures and instrumentation of experimental chemistry. It aims to develop the skills needed for effective work on future chemical laboratory projects such as the Major Qualifying Project. The work of the year develops sequentially.

CH 2640. EXPERIMENTAL CHEMISTRY I: INSTRUMENTAL ANALYSIS.
Cat. I
This laboratory course focuses on the application of modern instrumental methods of analysis to chemical, biochemical and environmental problems. Practical experience is gained in quantitative electrochemistry, ultraviolet-visible spectrophotometry, fluorometry and bioluminescence, high performance liquid chromatography, and capillary electrophoresis. Principles of experimental design and execution are developed as student teams select a chemical, biochemical or environmental problem, formulate an approach, conduct the analysis, and present findings to the class. Methods of data analysis and common statistical approaches are emphasized throughout the course.

Recommended background: CH 1010, CH 1020, CH 1030, CH 1040.

CH 2650. MODERN PHYSICAL CHEMISTRY METHODS.
Cat. I
This laboratory course emphasizes principles, techniques, and instrumentation employed in modern physical chemistry with a view towards applications throughout the molecular sciences. Investigations include chemical thermodynamics and phase equilibria; gas-phase, solution-phase, and interfacial reaction kinetics and dynamics; and molecular modeling of small molecules. Emphasis includes data collection, interpretation, error analysis, and write-up.

Recommended background: Fundamentals in chemistry (see CH 1010 – CH 1040), knowledge in thermodynamics (see CH 3510).

CH 2660. ORGANIC SYNTHESIS AND ANALYSIS LABORATORY.
Cat. I
The emphasis in CH 2660 is on fundamental techniques essential for the synthesis, purification, and characterization of organic compounds. These techniques include setting up, running and monitoring reactions, isolation and purification by solvent extraction, crystallization, distillation, and chromatographic techniques, followed by determination of physical properties and characterization by infrared (IR) and nuclear magnetic resonance (NMR) spectroscopy. Micro-synthetic methods and multi-step synthesis are introduced. This course differs from CH 2360 by providing in-depth experience with spectroscopic characterization of molecular structure and hands-on training operating core instruments in addition to methods of organic synthesis. This course is required for students majoring in chemistry, and is recommended for students majoring in biochemistry and disciplines outside of chemistry that desire a strong background in methods of organic synthesis and characterization.

Recommended background: Fundamentals of chemistry (see CH 1010, CH 1020, CH 1030) and chemical characterization techniques (see CH 1040), basic chemistry laboratory techniques (e.g., basic chemical synthesis, spectral analysis and chemical separation skills).

CH 2670. INVESTIGATION OF COORDINATION COMPLEXES THROUGH INQUIRY.
Cat. I
The synthesis, isolation, and characterization of inorganic compounds are emphasized. Syntheses of main group compounds, classical transition metal complexes, and organotransition metal compounds are included. In addition to reinforcing and building on standard techniques of synthesis and characterization, several new techniques are introduced: synthesis under inert atmosphere, measurement of magnetic susceptibility by NMR, and cyclic voltammetry. Some exposure to 13C NMR is also provided. The final experiment of the course requires the student to design a synthesis for a compound selected from a list provided, based on strategies learned in the course.

Recommended background: Principles of inorganic chemistry, chemical bonding and reactions, thermodynamic stability of inorganic species, solubility and precipitation of inorganic compounds. Advanced chemistry laboratory skills (see CH 2660)

INORGANIC AND PHYSICAL CHEMISTRY COURSES

CH 3410. STRUCTURE, BONDING, AND REACTIVITY IN INORGANIC CHEMISTRY.
Cat. I
This course provides the fundamental understanding of atomic, molecular and solid state structures and properties. Orbital structures of atoms, symmetry of molecules and point groups are used to understand chemical bonding and reactions. Various acid-base concepts are explored to analyze the acidity of cations and basicity of anions, solubility and precipitations of inorganic compounds, and metal-ligand binding affinities. Redox properties are discussed using Pourbaix diagrams. Thermodynamic stabilities of inorganic species are discussed using acid-base and redox concepts and thermochemical analyses are used to analyze chemical reactivity at atomic, molecular, and solid state level.

Recommended background: Firm understanding of general chemistry topics (CH 1010 – CH 1030)

CH 3510. CHEMICAL THERMODYNAMICS.
Cat. I
The content of this course will be the development of the principles of classical thermodynamics. The laws of thermodynamics will be developed by using a series of increasingly complex model systems and a universal equation of state is formulated which incorporates the relationships illustrated by these model systems. Using this equation it will be possible to appreciate that thermodynamic laws are applicable to all systems of matter, regardless of their complexity. Finally, the principles developed are applied to problems of a chemical nature, focusing on predicting the spontaneity of chemical reactions.

The material in this course will be of greatest interest to those students enrolled in the basic sciences including biology, chemistry, and physics, and in applied fields such as chemical engineering, materials science and biotechnology.

Recommended background: Students should be familiar with the material covered in the general chemistry sequence CH 1010-1040, and calculus including multi variables.

CH 3530. QUANTUM CHEMISTRY.
Cat. I
An introduction to quantum mechanics with applications to atomic and molecular species. The course will be developed systematically beginning with the postulates of quantum mechanics. The Schroedinger equation will be applied to systems such as the particle in a box, the rigid rotor, the harmonic oscillator and the hydrogen atom. Emphasis will be given to a quantum mechanical description of multielectron atoms, molecular bonding and spectroscopy.

Recommended background: a solid foundation in elementary physics and calculus.

This course is normally for students in their third year.

CH 3550. CHEMICAL DYNAMICS.
Cat. I
This course deals in a general way with the interactions between energy and molecules, and considers how energetic and structural considerations affect the outcome of molecular interactions. The manipulation of kinetic data and results is stressed. Selected topics from both organic and inorganic chemistry are analyzed in terms of reaction thermodynamics, rates and mechanisms.

Students are expected to be familiar with thermodynamics, equilibria, reaction rates and the Periodic Table of the elements.

The following three courses, CH 4110, CH 4120, and CH 4130, are a three-term sequence intended to provide a strong emphasis in biochemistry. As background for this sequence, CH 1010, CH 1020, CH 1030, CH 1040, CH 2310, CH 2320, and CH 2330, or their equivalents, are recommended.

BIOCHEMISTRY COURSES

CH 4110. PROTEIN STRUCTURE AND FUNCTION.
Cat. I
The fundamental concepts of protein architecture and dynamics are presented with an emphasis on the functional outcomes of chemistry coordinated in three dimensional space. Catalytic mechanics and enzyme function are outlined in detail. Current methods in the determination of enzyme structure and function will be discussed, and students will use common tools in macromolecular analysis and structural modeling. Case studies in enzyme dysfunction, disease, and current research will be used throughout the course.

Recommended background: Familiarity with organic chemistry topics including functional groups, nucleophilic addition and substitution reactions, stereochemistry, and carbonyl chemistry. General knowledge of cellular architecture is also recommended. See CH 2310, CH 2320, CH 2330, and BB 2550 or equivalent.

CH 4120. LIPIDS AND BIOMEMBRANE FUNCTIONS.
Cat. I
Oriented around biological membranes, this course begins with a description of lipids and proteins forming biomembranes. Permeability and the mechanism of transmembrane mass transport are presented. Transport of electrons and redox equivalents is explained within the context of aerobic production of ATP and plant photosynthesis. Finally the transport of information across biomembranes in signal transduction and neurotransmission are discussed.

Recommended background: Knowledge of organic chemistry fundamentals as well as concepts including protein structure and folding, catalytic mechanics, enzyme kinetics, and ATP synthesis and hydrolysis mechanisms. See CH 2310, BB 2550, and CH 4110 or equivalent.

CH 4130. NUCLEIC ACIDS AND BIOINFORMATION.
Cat. I
This course presents the structure and function of DNA. Precursors and biomolecules that give rise to DNA, the mechanism of DNA replication, RNA synthesis, and protein synthesis are described in detail. In addition to mechanistic studies, regulation of these processes is covered as well as those of genetic mutation, DNA repair, and epigenetics.

Recommended background: Knowledge of organic chemistry fundamentals as well as concepts including protein structure and folding, catalytic mechanics, enzyme kinetics, and ATP synthesis and hydrolysis mechanisms. See CH 2310, CH 2320, CH 2330, BB 2550, and CH 4110 or equivalent.

CH 4140. METABOLISM AND DISEASE.
Cat. I
This course presents a thorough analysis of the most relevant metabolic processes in cells. The catabolism of sugars and lipids will be presented in the context of energy generation and storage. Nucleotide and amino acid metabolism will discussed as building blocks for large biomolecules. Throughout the course the links between metabolism, hereditary pathologies, as well as risk of metabolic imbalances such as diabetes and obesity will be presented.

Recommended background: Familiarity with organic chemistry topics including functional groups, nucleophilic addition and substitution reactions, stereochemistry, and carbonyl chemistry. General knowledge of cellular architecture is also recommended. See CH 2310, CH 2320, CH 2330, and BB 2550 or equivalent.

Specific concepts that we will discuss are: Glucose and glycogen metabolism; Gluconeogenesis; Citric Acid Cycle; Lipid, amino acid and nucleotide metabolisms; Mammalian Fuel Metabolism: Integration and Regulation.

CH 4150. ENZYMOLOGY AND PROTEIN CHARACTERIZATION LABORATORY.
Cat. I
The experiments in this laboratory course have been designed to acquaint the students with the basic skills necessary to perform biochemical studies. The course will cover, for instance, protein purification, subcellular fractionation, enzyme kinetics (Km, Vmax, specific activity, effector-protein interaction, etc.), exclusion and ion exchange chromatography, and electrophoresis.

Recommended background: Knowledge of organic chemistry fundamentals as well as concepts including protein structure and folding, catalytic mechanics, enzyme kinetics, and ATP synthesis and hydrolysis mechanisms. See CH 2310, BB 2550, and CH 4110 or equivalent.

CH 4160. MEMBRANE BIOPHYSICS.
Cat. II
This course will focus on different areas of biophysics with special emphasis on membrane phenomena. The biomedical-biological importance of biophysical phenomena will be stressed. The course will begin with the introduction of the molecular forces relevant in biological media and subsequently develop the following topics: Membrane Structure and Function; Channels, Carriers and Pumps; Nerve Excitation and related topics; and Molecular Biophysics of Motility.

Recommended background: prior knowledge of Biochemistry (CH 4110, CH 4120), Mechanics (PH 1110) and Electricity (PH 1120).

This course will be offered in 2019-20, and in alternating years thereafter.

CH/BB 4170. EXPERIMENTAL GENETIC ENGINEERING.
Cat. I
This laboratory course focuses on modern DNA technologies and general applications of gene manipulation. Topics include gene amplification and recombination, promoter and plasmid engineering, gene expression and analysis, model systems, CRISPR, genomics and transgenics. Experiments in this course are integrated into an overall genetic engineering project throughout the term that will involve techniques such as electrophoresis, quantitative spectrofluorimetry, and real-time quantitative PCR. Methods of data analysis, common statistical approaches and technical writing will be emphasized throughout the course.

Recommended background: Knowledge of organic chemistry fundamentals as well as biochemical concepts including DNA replication and recombination, RNA synthesis and protein synthesis. Familiarity with cellular architecture is also recommended. See CH 2310, BB 2550, BB 4010 and CH 4110 or equivalent.

CH/BB 4190. REGULATION OF GENE EXPRESSION.
Cat. I
Through lectures, problem sets, reading and discussion, and presentations this course will help elucidate for students the processes that allow regulated gene expression, mechanisms used in each type of regulation, and methods and techniques used for investigation of regulatory mechanisms. Readings from the current original research literature will explore the growing use of model systems and “omics” level approaches to enhance our ever expanding understanding of the gene regulatory mechanisms. The development of cell-based therapeutics and genetic engineering as they relate to gene regulation will be introduced.

Recommended background: a working knowledge of concepts in biochemistry and molecular genetics (CH 4110, 4120, 4130 and BB 4010 or equivalent)

ADVANCED CHEMISTRY COURSES

CH 4330. ORGANIC SYNTHESIS.
Cat. II
Modern synthetic methods as applied to the construction of societally relevant target molecules will be the focus of this course. Discussions may emphasize the logic and strategy in synthetic approaches toward active pharmaceutical ingredients, agrochemicals, fine chemicals, materials, and other targets of interest. The analysis of current examples from the primary literature will draw attention to the most state-of–the-art synthetic tactics.

Recommended for graduate students and undergraduates who have a basic understanding of the principles governing organic reactions, such as those covered in CH2310, CH2320, and CH2330.

This course will be offered in 2020-21 and alternate years thereafter.

CH 4420. APPLICATION OF MOLECULAR ORBITAL THEORY TO METAL COMPLEXES.
Cat. I
Complexes of the transition metals are discussed. Covered are the electronic structures of transition metal atoms and ions, and the topological and electronic structures of their complexes. Symmetry concepts are developed early in the course and used throughout to simplify treatments of electronic structure. The molecular orbital approach to bonding is emphasized. The pivotal area of organotransition metal chemistry is introduced, with focus on complexes of carbon monoxide, metal-metal interactions in clusters, and catalysis by metal complexes. Recommended background: CH 1010 - CH 1040, CH 2640 - CH 2670, CH 3410, CH 3530, and CH 3550.

Recommended background: Fundamental understanding of atomic, molecular and solid state structures and properties. Thermodynamic stabilities of inorganic species. Acidity, solubility and precipitation of inorganic compounds (see CH 3410).

CH 4520. CHEMICAL STATISTICAL MECHANICS.
Cat. II
This course deals with how the electronic, translational, rotational and vibrational energy levels of individual molecules, or of macromolecular systems, are statistically related to the energy, entropy, and free energy of macroscopic systems, taking into account the quantum mechanical properties of the component particles. Ensembles, partition functions, and Boltzmann, Fermi-Dirac, and Bose-Einstein statistics are used. A wealth of physical chemical phenomena, including material related to solids, liquids, gases, spectroscopy and chemical reactions are made understandable by the concepts learned in this course.

Recommended background: CH 3510 and CH 3530, or equivalent, and mathematics through differential and integral calculus.

This course will be offered in 2019-20, and in alternating years thereafter.

Graduate Chemistry Courses of Interest to Undergraduates

CH 516. CHEMICAL SPECTROSCOPY.
Advanced topics in identification of organic species and determination of molecular structure by spectroscopic methods.

Methods covered include ^{1}H- and ^{13}C-NMR, mass spectrometry and infrared and UV-visible spectroscopy. This course is concerned only with interpretation of spectra and does not cover techniques obtaining them; there is no laboratory.

CH 536. THEORY AND APPLICATIONS OF NMR SPECTROSCOPY.
This course emphasizes the fundamental aspects of 1D and 2D nuclear magnetic resonance spectroscopy (NMR). The theory of pulsed Fourier transform NMR is presented through the use of vector diagrams. A conceptual nonmathematical approach is employed in discussion of NMR theory. The course is geared toward an audience which seeks an understanding of NMR theory and an appreciation of the practical applications of NMR in chemical analysis. Students are exposed to hands-on NMR operation. Detailed instructions are provided and each student is expected to carry out his or her own NMR experiments on a Bruker AVANCE 400 MHz NMR spectrometer.

CH 538. MEDICINAL CHEMISTRY.
This course will focus on the medicinal chemistry aspects of drug discovery from an industrial pharmaceutical Research and Development perspective. Topics will include Chemotherapeutic Agents (such as antibacterial, antiviral and antitumor agents) and Pharmacodynamic Agents (such as antihypertensive, antiallergic, antiulcer and CNS agents).

Recommended background: CH 2310, CH 2320, and CH 2330.

CH/CHE 554. MOLECULAR MODELING.
This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical applications, for researchers who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a background at the introductory level in quantum mechanics is highly desirable. Methods to be explored include density functional theory, ab initio methods, semiempirical molecular orbital theory, and visualization software for the graphical display of molecules.

CH 555. ADVANCED TOPICS.
A course of advanced study in selected areas whose content and format to suit the interest and needs of faculty and students.

CIVIL AND ENVIRONMENTAL ENGINEERING

CE 1030. CIVIL ENGINEERING AND COMPUTER FUNDAMENTALS.
Cat. I
This course introduces students to basic fundamentals of civil engineering, group dynamics, oral presentation skills, engineering report writing techniques, and uses of the computer. Basics of structural engineering, geotechnical engineering, environmental engineering, surveying, materials, and construction engineering and management are presented in this course through a collaborative group teaching approach. Background is provided to gain competence in operating systems, editors, and spreadsheets. Student groups complete weekly computer laboratory projects and develop oral presentations and written reports.

No previous computer use skills are required or assumed. This course is recommended for freshman or sophomore students.

CE 2000. ANALYTICAL MECHANICS I.
Cat. I
This fundamental civil engineering course provides an introduction to the analysis of structures in static equilibrium. The focus of this course is a classical analysis of concurrent and non-concurrent equilibrium. A variety of engineering problems including trusses, machines, beams, rigid frames, and hydraulic structures involving concentrated and distributed loading systems are analyzed for external reactions and internal forces.

CE 2001. ANALYTICAL MECHANICS II.
Cat. I
This course provides an introduction to the relationship between analysis, design, and the behavior of materials under load. Theory and applications are developed that utilize simple and combined stress-strain behavior of members subjected to axial, torsional, and flexural loadings, with applications to beams, trusses, rigid frames, shafts, and tension and compression structures.

Recommended background: CE 2000.

CE 2002. INTRODUCTION TO ANALYSIS AND DESIGN.
Cat. I
This course develops an understanding of classical and modern structural analysis. Topics include loading systems, and the analysis of statically determinate and statically indeterminate beams, frames, trusses, structural floor systems for buildings, bridges, and other structural assemblies.

Recommended background: CE 2000 and CE 2001.
Suggested background: CE 1030.

CE 2020. SURVEYING.
Cat. I
This course develops fundamental skills in the theoretical and practical aspects of plane surveying through the use and care of modern instruments and the associated computations. Topics include the classification of errors incurred in observed field data and necessary correction applications, the use and care of surveying equipment, traversing, differential leveling, stadia and mapping, and electronic data transfer. Computer applications are used where appropriate.

CE 3006. DESIGN OF STEEL STRUCTURES.
Cat. I
This course covers the theory and practice of structural steel design. The structural design process for beams, columns, trusses, frames, and connections is based on Load and Resistance Factor Design (LRFD) specifications of the American Institute of Steel Construction.

Recommended background: CE 2002 and CE 3010.
Suggested background: CE 1030.

CE 3008. DESIGN OF REINFORCED CONCRETE STRUCTURES.
Cat. I
This course covers the theory and practice of reinforced concrete design. The structural design process for beams, columns, slabs, frames, flat slabs, footings, and retaining walls uses the ultimate strength design codes of the American Concrete Institute.

Recommended background: CE 2002 and CE 3010.
Suggested background: CE 1030.

CE 3010. STRUCTURAL ENGINEERING.
Cat. I
This course provides an understanding of the practice of structural engineering. It builds upon the fundamental skills developed in CE 2000, CE 2001, and CE 2002 to present the principles of structures and their elements. The course provides a perspective for dealing with the issues of strength, stiffness, and stability. Although wood is the principle material used to develop the study of the interrelationship between analysis and design of structural systems, structural steel and reinforced concrete systems are also discussed. It also introduces students to the use of building codes for design criteria. The role of the structural engineer in the design process and cost factors are also discussed.

Recommended background: CE 2000, CE 2001, and CE 2002.
Suggested background: CE 1030.

CE 3020. PROJECT MANAGEMENT.
Cat. I
This course presents the fundamental concepts and process of project management applied to public and private works. The principle focus of the course is the management of civil engineering projects including planning, scheduling, organization and control, as well as management concepts of leadership, motivation, trust, project team development, division of work, and conflict resolution. Ancillary engineering and construction practices involving financial practices, construction documents, contract negotiation and administration, quality and safety control, insurance and bonding are covered.

Recommended background: CE 1030.

CE 3022. LEGAL ASPECTS OF PROFESSIONAL PRACTICE.
Cat. I
The course focuses on the legal underpinnings that regulate the design and execution of construction projects and the relations between their participants. The subject is presented according to the various phases of a construction project, from inception to handover. The overall objective is to develop an awareness of the legal aspects that regulate the exercise of the architectural and civil engineering profession and of the environmental constraints of construction. Topics such as permitting process, design/engineering services and ethical issues are included.

Some sections of this course may be offered as Writing Intensive (WI)

CE 3024. CONTROL SURVEYING.
Cat. II
This course presents the principles and field procedures required in the design of vertical and horizontal control networks for large building and construction projects.

Recommended background: CE 2020.
This course will be offered in 2020-21, and in alternating years thereafter.

CE 3025. PROJECT EVALUATION.
Cat. I
In this course students are provided with a systematic framework for evaluating the economic sustainability and financial aspects of a building investment through its life cycle: project definition, design, construction and operation. The course develops according to several interrelated topics: budgeting (square foot cost and parametric estimating) and economic feasibility analysis, financing mechanisms, cash flow analysis, (time-value -of -money factors, present worth and rate of return), life-cycle assessment (environmental impact analysis), taxes, depreciation and regulations as well as consideration of risks and uncertainties.

Recommended background: AREN 2023.
This course will be offered in 2020-21, and in alternating years thereafter.

CE 3026. MATERIALS OF CONSTRUCTION.
Cat. I
This course provides an understanding of the use and acquisition of engineering properties of construction materials. Topics include relationships between the structure of materials, their engineering properties, and the selection of suitable materials for applications involving strength, durability, and serviceability. Experimental laboratory procedures including design of experiments, data collection, analysis, and representation, and report writing are an integral part of the work.
Recommended background: CE 1030 and CE 2001.
Some sections of this course may be offered as Writing Intensive (WI).

CE 3030. FUNDAMENTALS OF CIVIL ENGINEERING AUTOCAD.
Cat. I
This course introduces Civil Engineering students to fundamental uses of the AutoCAD software package. Basic two dimensional drawing techniques are covered. Advanced topics that may be covered include three dimensional drawing, rendering and animation. Students are required to become familiar with AutoCAD.
Knowledge of the subject matter in at least two civil engineering design courses is expected background for this course.

CE 3031. BUILDING INFORMATION MODELING: SOFTWARE TOOLS AND PRINCIPLES.
Cat. I
This course introduces students to fundamental software applications for design and construction planning throughout the different phases of the development of civil engineering projects in a collaborative fashion as established by the principles of Building Information Modeling. The course covers the principles of basic 3D software environments, object creation and manipulation, assemblies of objects, surface and terrain modeling, building modeling, geographic and building information databases. Emphasis is given to the adaptability of this software to changes in design and to the production of graphic design documentation. Application software such as AutoCAD Civil 3D, Autodesk Revit and Navisworks are used in this course. Recommended background: CE 1030 or AREN 3001 or equivalent.

CE 3041. SOIL MECHANICS.
Cat. I
This is an introductory course dealing with the science and technology of earth materials with an emphasis on fundamental concepts of particulate mechanics. The topics which are discussed include fluid flow through porous media, deformation and shear characteristics of soil, consolidation, lateral earth pressure, and slope stability.
Recommended background: CE 2000 and CE 2001.
Suggested background: GE 2341.

CE 3044. FOUNDATION ENGINEERING.
Cat. I
Foundation engineering is a study of the applications of the principles of soil mechanics and structural theory to the analysis, design and construction of foundations for engineering works with the emphasis on the soil engineering aspects of soil structure interaction. Subsurface exploration techniques, design of rigid and flexible retaining structures, and design of, shallow and deep foundations are considered. Although the course deals mainly with aspects of the design of buildings and bridges, certain parts of the course (design of temporary trench bracing, for example) are very relevant to construction engineering.
Recommended background: CE 3041.
Suggested background: CE 3008.

CE 3050. TRANSPORTATION: TRAFFIC ENGINEERING.
Cat. I
This course provides an introduction to the field of transportation engineering with particular emphasis on traffic engineering. Topics covered include a description of the transportation industry and transportation modes; characteristics of drivers, pedestrians, vehicles and the roadway; traffic engineering studies, highway safety, principles of traffic flow, intersection design and control, capacity analysis, and level of service analysis.
Suggested background: CE 2020.

CE 3051. TRANSPORTATION: PAVEMENT ENGINEERING.
Cat. I
This course provides an introduction to concepts required for design construction and management of pavements. Topics include Highway Drainage, Soil Engineering for Highway Design, Bituminous Materials, Design of Flexible and Rigid Pavements and Pavement Management. Knowledge of the subject matter in CE 3050 is helpful but not required.

CE 3059. ENVIRONMENTAL ENGINEERING
Cat. I
This course provides an introduction to engineering aspects of environmental quality control. Students will learn fundamental science and engineering principles needed for environmental engineering, including concepts in chemistry, biology, physics, mass conservation, kinetics and reactor design. These principles are then applied to environmental engineering problems, including modeling of pollutants in natural systems and design of unit processes in engineered systems. Topics covered include environmental regulations, surface and ground water quality, drinking water treatment, wastewater treatment, air pollution, and hazardous waste management.
Recommended background: college-level chemistry.

CE 3060. WATER TREATMENT.
Cat. I
This course provides in-depth coverage of processes used in water treatment. Topics include: review of water chemistry and drinking water standards, impurities in natural waters, aeration, water softening coagulation, flocculation, sedimentation, filtration, disinfection, taste and odor control, corrosion control, and iron and manganese removal.
Recommended background: CE 3059 and ES 3004.

CE 3061. WASTE WATER TREATMENT.
Cat. I
This course provides in-depth coverage of processes used in wastewater treatment. Topics include: review of water quality standards, wastewater characteristics, application of biochemical oxygen demand, sources and effects of pollution, physical, chemical, and biological wastewater treatment processes, and waste sludge management.
Recommended background: CE 3059 and ES 3004.

CE 3062. HYDRAULICS.
Cat. I
This course provides a background for applying the principles of fluid mechanics to analyze and design hydraulic and fluid flow systems for projects related to water resources and civil and environmental engineering. Topics include hydraulics in pipes and closed systems, open channels and rivers, water supply systems and water distribution networks, pump systems and turbines, wastewater collection and treatment systems, and coastal and other natural environmental systems. Course content includes water quality and energy considerations, as well as the development and application of hydraulic models.
Recommended background: ES 3004.

CE 3070. URBAN AND ENVIRONMENTAL PLANNING.
Cat. I
This course introduces to the student the social, economic, political, and environmental factors that affect the complex relationship between the built and natural environment. By using the principles of sustainable development and the procedures of planning, the optimal development pattern may be examined, and the infrastructure (roads, water supply systems, waste-water treatment systems, shopping malls, etc.) necessary to support present and future growth patterns may be determined. The information necessary in planning, which involves conscious procedures of analysis, formulation of alternative solutions, rational assessment and deliberate choice in accordance with evaluation criteria, is obtained through extensive reading. As such, the course introduces a variety of topics of concern to engineers and environmental scientists. The course is intended not only for civil engineering majors, but also for students preparing for an IQP in areas of urban or environmental concerns.
Some sections of this course may be offered as Writing Intensive (WI).

CE 3074. ENVIRONMENTAL ANALYSIS.
Cat. I
This course provides a background in the principles and techniques of assessing areas of natural environment and applying environmental assessments to evaluate the inherent suitability of these areas for sustainable urban and resource-based uses. Topic areas include basic concepts in sustainability, landscape characterization and analysis, and environmental impact assessment and planning. The concepts and techniques developed in this course are useful for land use planning, site design, natural resources management, and the determination of the impact of engineering projects on the environment.
Suggested background: CE 3059 or CE 3070.

CE 4007. MATRIX ANALYSIS OF STRUCTURES.
Cat. II
This course presents the principles of matrix analysis of structural elements and systems; fundamentals of matrix algebra, solution of simultaneous equations, matrix inversion; analysis of plane trusses, method of joints; displacement method, principle of virtual work, analysis of continuous beams, analysis of plane frames, plane trusses, analysis of building frames and bridges; computer aided structural analysis and principles of software development.
Recommended background: CE 2002.
This course will be offered in 2019-20, and in alternating years thereafter.

CE 4017. PRESTRESSED CONCRETE DESIGN.
Cat. II
This course covers analysis and design aspects of prestressed concrete structural elements and systems: principles of prestressing, materials for prestressing, high strength steel, flexural analysis and design methods; allowable stress and strength design methods; design of beams, load balancing, partial prestressing and cracking moment; design for shear, partial loss of prestress; deflections of prestressed concrete and precast construction; connections.
Recommended background: CE 2002 and CE 3026.
Suggested background: CE 3008.
This course will be offered in 2019-20, and in alternating years thereafter.

CE 4054. TRANSPORTATION: INFRASTRUCTURE MATERIALS LABORATORY.
Cat. II
This laboratory-based course introduces standard laboratory soil and asphalt materials testing procedures, and effect of physical properties on performance of soils and asphalt pavements. The tests which are performed include: grain size analysis, Atterberg limits, specific gravity, permeability, compaction, compression and consolidation, and triaxial shear for soils, and penetration, consensus and source properties of aggregate, compaction, resilient modulus, indirect tensile strength and nondestructive testing of soils and hot mix asphalt. Instruction is provided through lecture, laboratory work and field trip.
Recommended background: CE 3041 and CE 3052.
This course will be offered in 2019-20, and in alternating years thereafter.

CE 4060. ENVIRONMENTAL ENGINEERING LABORATORY.
Cat. I
This course familiarizes students with the laboratory studies used to obtain the design parameters for water and wastewater treatment systems. The topics include laboratory experiments dealing with physical, chemical, and biological treatment systems.
Recommended background: CE 3060 and CE 3061.

CE 4061. HYDROLOGY.
Cat. II
This course introduces the concepts and principles governing the distribution and transport of water in the environment, and also provides a background for quantifying hydrologic processes as required for the development of water resources projects. Topics include the hydrologic cycle, precipitation, evaporation and transpiration, infiltration, runoff analysis, streamflow, hydrologic routing, statistics and probability in hydrology, and the quantification of hydrologic processes for water quality protection. The course introduces field techniques and the use of hydrologic models for solving problems in water resources and hydrology.
Recommended background: ES 3004.
This course will be offered in 2020-21, and in alternating years thereafter.

CE/CHE 4063. TRANSPORT & TRANSFORMATIONS IN THE ENVIRONMENT.
Cat. II
In this course, students will learn to make quantitative relationships between human activities and the effects on water, soil, and air in the environment. Students will learn the scientific and engineering principles that are needed to understand how contaminants enter and move in the environment, how compounds react in the environment, how to predict their concentrations in the environment, and how to develop solutions to environmental problems.
Topics to be covered may include water quality engineering (including microbial interactions), air quality engineering, and hazardous waste management.
Recommended Background: familiarity with transport phenomena, such as in ES 3004 (Fluid Mechanics) and ES 3002 (Mass Transfer), and familiarity with reaction kinetics and reactor design, such as through CHE 3201 (Kinetics and Reactor Design). Background such as CE 3059 (Environmental Engineering), CE 3060 (Water Treatment), or CE3061 (Wastewater Treatment) is suggested.
This course will be offered in 2020-21, and in alternating years thereafter.

CE 4071. LAND USE DEVELOPMENT AND CONTROLS.
Cat. I
The purpose of this course is to provide an understanding of the regulatory framework under which land is developed and the built environment is designed. The quality of our environment depends upon the development which is permitted to take place and the controls which direct that development. Through this course, the student will learn the principles, methods, and techniques which a planner or engineer may use to plan and design the highest and best uses and development of land. In particular, the use and limits of zoning, special permits, subdivision control, and other tools with which a developer or planner should be familiar will be examined in detail.
Some sections of this course may be offered as Writing Intensive (WI).

CE 4600. HAZARDOUS AND INDUSTRIAL WASTE MANAGEMENT.
Cat. II
This course will cover concepts and techniques for handling hazardous and industrial wastes. Regulations governing hazardous waste, water & soil remediation concepts, and the fundamentals of waste treatment processes will be discussed. Instruction will be provided through lectures, fieldtrips, practitioner seminars, and class problem solving sessions.
Recommended background: ES 3004 and CE 3059.
This course will be offered in 2019-20, and in alternating years thereafter.

COMPUTER SCIENCE

CS 1004. INTRODUCTION TO PROGRAMMING FOR NON-MAJORS.
Cat. I
This course introduces students to the fundamental principles of programming in imperative and scripting languages. Topics include control structures, iterators, functional decomposition, and basic data structures (such as records). Students will be expected to implement, test, and debug programs. Through the use of compelling applications and lab exercises, students will learn how to interface with external data systems and control devices.
Recommended background: none. All Computer Science students and other students wishing to prepare for 3000-level courses in Computer Science should take CS 1101/1102 instead of CS 1004. This course provides sufficient background for CS 2301 Systems Programming for Non-Majors.

CS 1101. INTRODUCTION TO PROGRAM DESIGN.
Cat. I
This course introduces principles of computation and programming with an emphasis on program design. Topics include the design, implementation, and testing of programs that use a variety of data structures (such as structures, lists, and trees), functions, conditionals, recursion, and higher-order functions. Students will be expected to design simple data models, and implement and debug programs in a functional programming language.
Recommended background: none. Either CS 1101 or CS 1102 provides sufficient background for further courses in the CS department. Undergraduate credit may not be earned for both this course and CS 1102.

CS 1102. ACCELERATED INTRODUCTION TO PROGRAM DESIGN.
Cat. I
In the first half of the term, this course covers the same functional programming material as CS 1101 at roughly twice the pace. The second half of the term is a preview of selected advanced Computer Science topics, such as the design and implementation of application-specific languages, macros, programming with the HTTP protocol, and continuation-passing style. Students will be expected to complete an open-ended individual programming project.
Recommended background: Substantial prior programming experience (including functions, recursion, and lists, as would be covered in high-school Advanced Placement Computer Science A courses, but not necessarily AP CS Principles courses). Either CS 1101 or CS 1102 provides sufficient background for further courses in the CS department. Undergraduate credit may not be earned for both this course and CS 1101.

CS 2011. INTRODUCTION TO MACHINE ORGANIZATION AND ASSEMBLY LANGUAGE.
Cat. I
This course introduces students to the structure and behavior of modern digital computers and the way they execute programs. Machine organization topics include the Von Neumann model of execution, functional organization of computer hardware, the memory hierarchy, caching performance, and pipelining. Assembly language topics include representations of numbers in computers, basic instruction sets, addressing modes, stacks and procedures, low-level I/O, and the functions of compilers, assemblers, linkers, and loaders. The course also presents how code and data structures of higher-level languages are mapped into the assembly language and machine representations of a modern processor. Programming projects will be carried out in the C language and the assembly language of a modern processor.
Recommended background: CS 2301 or CS 2303, or a significant knowledge of C/C++.

CS 2022/MA 2201. DISCRETE MATHEMATICS.
Cat. I
This course serves as an introduction to some of the more important concepts, techniques, and structures of discrete mathematics providing a bridge between computer science and mathematics. Topics include sets, functions and relations, propositional and predicate calculus, mathematical induction, properties of integers, counting techniques, and graph theory. Students will be expected to develop simple proofs for problems drawn primarily from computer science and applied mathematics.
Recommended background: None.

CS 2102. OBJECT-ORIENTED DESIGN CONCEPTS.
Cat. I
This course introduces students to an object-oriented model of programming. Building from the design methodology covered in CS 1101/CS 1102, this course shows how programs can be decomposed into classes and objects. By emphasizing design, this course shows how to implement small defect-free programs and evaluate design decisions to select an optimal design under specific assumptions. Topics include inheritance, exceptions, interface, design by contract, basic design patterns, and reuse. Students will be expected to design, implement, and debug object-oriented programs composed of multiple classes and over a variety of data structures.
Recommended background: CS 1101 or CS 1102.

CS 2103. ACCELERATED OBJECT-ORIENTED DESIGN CONCEPTS.
Cat.I.
This course covers the data structures and general program-design material from CS2102, but assumes that students have significant prior experience in object-oriented programming. The course covers object-oriented design principles and data structures more deeply and at a faster pace than in CS 2102. Students will be expected to design, implement, test, debug, and critique programs both for correctness and adherence to good object-oriented design principles. The course is designed to strengthen both the design skills and algorithmic thinking of students who already have a foundation in object-oriented programming. Recommended background: CS 1101 or CS 1102 and significant prior experience writing object-oriented programs from scratch. Advanced Placement Computer Science A courses should provide sufficient background; students from AP CS Principles courses or gentler introductions to Java Programming are advised to take CS2102 instead. Students may receive credit for only one of the following three courses: CS 2102, CS 210X, CS 2103.

CS 2119. APPLICATION BUILDING WITH OBJECT-ORIENTED CONCEPTS.
Cat. I
This course introduces students to an object-oriented model of programming, with an emphasis on the programming approaches useful in creating software applications. Students will be expected to design, implement, and debug object-oriented programs. Topics include inheritance, user interfaces, and database access. This course is for non-CS majors with prior programming experience and an interest in building software applications.
Recommended background: Some programming experience such as found in CS 1101, CS 1102, or CS 1004.

CS 2223. ALGORITHMS.
Cat. I
Building on a fundamental knowledge of data structures, data abstraction techniques, and mathematical tools, a number of examples of algorithm design and analysis — worst case and average case — will be developed.
Topics include greedy algorithms, divide-and-conquer, dynamic programming, heuristics, and probabilistic algorithms. Problems will be drawn from areas such as sorting, graph theory, and string processing. The influence of the computational model on algorithm design will be discussed.
Students will be expected to perform analysis on a variety of algorithms.
Recommended background: CS 2102 or CS 2103, and CS 2022.

CS 2301. SYSTEMS PROGRAMMING FOR NON-MAJORS.
Cat. I
This course introduces the C programming language and system programming concepts to non-CS majors who need to program computers in their own fields. The course assumes that students have had previous programming experience. It quickly introduces the major concepts of the C language and covers manual memory management, pointers and basic data structures, the machine stack, and input/output mechanisms. Students will be expected to design, implement, and debug programs in C.
Recommended background: CS 1101, CS 1102, or CS 1004 or previous experience programming a computer.
All Computer Science students and other students wishing to prepare for upper-level courses in Computer Science should take CS 2303 instead of CS 2301. Students who have credit for CS 2303 may not receive subsequent credit for CS 2301.

CS 2303. SYSTEMS PROGRAMMING CONCEPTS.
Cat. I
This course introduces students to a model of programming where the programming language exposes details of how the hardware stores and executes software. Building from the design concepts covered in CS 2102, this course covers manual memory management, pointers, the machine stack, and input/output mechanisms. The course will involve large-scale programming exercises and will be designed to help students confront issues of safe programming with system-level constructs. The course will cover several tools that assist programmers in these tasks. Students will be expected to design, implement, and debug programs in C++ and C. The course presents the material from CS 2301 at a fast pace and also includes C++ and other advanced topics.
Recommended background: CS 2102, CS 2103, or CS 2119 and/or substantial object-oriented programming experience.

CS 3013. OPERATING SYSTEMS.
Cat. I
This course provides the student with an understanding of the basic components of a general-purpose operating system. Topics include processes, process management, synchronization, input/output devices and their programming, interrupts, memory management, resource allocation, and an introduction to file systems. Students will be expected to design and implement a large piece of system software in the C programming language.
Undergraduate credit may not be earned both for this course and for CS 502.
Recommended background: CS 2303 or CS 2301, and CS 2011.

CS 3041. HUMAN-COMPUTER INTERACTION.
Cat. I
This course develops in the student an understanding of the nature and importance of problems concerning the efficiency and effectiveness of human interaction with computer-based systems.
Topics include the design and evaluation of interactive computer systems, basic psychological considerations of interaction, interactive language design, interactive hardware design, and special input/output techniques.
Students will be expected to complete several projects. A project might be a software evaluation, interface development, or an experiment.
Recommended background: CS 2102, CS 2103, or CS 2119.

CS 3043. SOCIAL IMPLICATIONS OF INFORMATION PROCESSING.
Cat. I
This course makes the student aware of the social, moral, ethical, and philosophical impact of computers and computer-based systems on society, both now and in the future.
Topics include major computer-based applications and their impact, human-machine relationships, and the major problems of controlling the use of computers.
Students will be expected to contribute to classroom discussions and to complete a number of significant writing assignments.
This course is recommended for juniors and seniors.
Recommended background: a general knowledge of computers and computer systems.

CS 3133. FOUNDATIONS OF COMPUTER SCIENCE.
Cat. I
This course introduces the theoretical foundations of computer science. These form the basis for a more complete understanding of the proficiency in computer science.

Topics include computational models, formal languages, and an introduction to compatibility and complexity theory, including NP-completeness.

Students will be expected to complete a variety of exercises and proofs.

Undergraduate credit may not be earned for both this course and for CS 5003.

Recommended Background: Discrete Mathematics (CS 2022 or equivalent), and Algorithms (CS 2223 or equivalent).

Students who have credit for CS 4121 may not receive credit for CS 3133.

CS 3431. DATABASE SYSTEMS I.
Cat. I
This course introduces the student to the design, use, and application of database management systems.

Topics include the relational data model, relational query languages, design theory, and conceptual data design and modeling for relational database design. Techniques that provide for data independence and minimal redundancy will be discussed.

Students will be expected to design and implement database system applications.

Undergraduate credit may not be earned both for this course and for CS 4431 or CS 542.

Recommended background: CS 2022 and either CS 2102, CS 2103, or CS 2119.

CS 3516. COMPUTER NETWORKS.
Cat. I
This course provides a broad view of computer networks. The course exposes students to all seven layers of OSI Reference Model while providing an introduction into newer topics such as wireless networking and Internet traffic concerns. The objective is to focus on an understanding of fundamental concepts of modern computer network architecture from a design and performance perspective. Topics covered include physical layer considerations, network protocols, wide area networks, local area networks, wireless networks, switches and routing, congestion, Internet traffic, and network security. Students will be expected to do extensive systems/network programming and will be expected to make use of simulation and measurement tools to gain an appreciation of current network design and performance issues. This course is also highly recommended for RBE and IMGD majors.

Recommended background: CS 2301 or CS 2303, or a significant knowledge of C/C++.

CS 3733. SOFTWARE ENGINEERING.
Cat. I
This course introduces the fundamental principles of software engineering. Modern software development techniques and life cycles are emphasized.

Topics include requirements analysis and specification, analysis and design, architecture, implementation, testing and quality, configuration management, and project management.

Students will be expected to complete a project that employs techniques from the topics studied.

This course should be taken before any course requiring a large programming project.

Undergraduate credit may not be earned both for this course and for CS 509.

Recommended background: CS 2102, CS 2103, or CS 2119.

CS 4032/MA 3257. NUMERICAL METHODS FOR LINEAR AND NONLINEAR SYSTEMS.
Cat. I
This course provides an introduction to modern computational methods for linear and nonlinear equations and systems and their applications.

Topics covered include solution of nonlinear scalar equations, direct and iterative algorithms for the solution of systems of linear equations, solution of nonlinear systems, and the eigenvalue problem for matrices. Error analysis will be emphasized throughout.

Recommended background: MA 2071. An ability to write computer programs in a scientific language is assumed.

CS 4033/MA 3457. NUMERICAL METHODS FOR CALCULUS AND DIFFERENTIAL EQUATIONS.
Cat. I
This course provides an introduction to modern computational methods for differential and integral calculus and differental equations.

Topics covered include interpolation and polynomial approximation, approximation theory, numerical differentiation and integration, and numerical solutions of ordinary differential equations. Error analysis will be emphasized throughout.

Recommended background: MA 2051. An ability to write computer programs in a scientific language is assumed. Undergraduate credit may not be earned for both this course and for MA 3255/CS 4031.

CS/IMGD 4100. ARTIFICIAL INTELLIGENCE FOR INTERACTIVE MEDIA AND GAMES.
Cat. II
Algorithms and programming techniques from artificial intelligence (AI) are key contributors to the experience of modern computer games and interactive media, either by directly controlling a non-player character (NPC) or through more subtle manipulation of the environment. This course will focus on the practical AI programming techniques currently used in computer games for NPC navigation and decision-making, along with the design issues that arise when AI is applied in computer games, such as believability and real-time performance. The course will also briefly discuss future directions in applying AI to games and media. Students will be expected to complete significant software development projects using the studied techniques.

Recommended background: object-oriented design concepts (CS 2102 or CS 2103), algorithms (CS 2223), and knowledge of technical game development (IMGD 3000)

This course will be offered in 2019-20, and in alternating years thereafter.

CS 4120. ANALYSIS OF ALGORITHMS.
Cat. II
This course develops the skill of analyzing the behavior of algorithms.

Topics include the analysis — with respect to average and worst case behavior — and correctness of algorithms for internal sorting, pattern matching on strings, graph algorithms, and methods such as recursion elimination, dynamic programming, and program profiling.

Students will be expected to write and analyze programs.

Undergraduate credit may not be earned both for this course and for CS 5084.

Recommended background: Algorithms (CS 2223 or equivalent), and some knowledge of probability.

This course will be offered in 2020-21, and in alternating years thereafter.

CS 4123. THEORY OF COMPUTATION.
Cat. II
Building on the theoretical foundations from CS 3133, this course addresses the fundamental question of what it means to be "computable," including different characterization of computable sets and functions.

Topics include the halting program, the Church-Turing thesis, primitive recursive functions, recursive sets, recursively enumerable sets, NP-completeness, and reducibilities.

Students will be expected to complete a variety of exercises and proofs.

Recommended Background: CS 3133.

This course will be offered in 2019-20, and in alternating years thereafter.

CS 4233. OBJECT-ORIENTED ANALYSIS AND DESIGN.
Cat. II
This Software Engineering course will focus on the process of Object-Oriented Analysis and Design. Students will be expected to complete a large number of exercises in Domain Modeling, Use Case Analysis, and Object-Oriented Design. In addition, the course will investigate Design Patterns, which are elements of reusable object-oriented software designs. This course will survey a set of design patterns and consider how these patterns are described and used to solve design problems.

Recommended Background: CS 2303 and CS 3733.

This course will be offered in 2020-21, and in alternating years thereafter.

CS 4241. WEBWARE: COMPUTATIONAL TECHNOLOGY FOR NETWORK INFORMATION SYSTEMS.
Cat. I
This course explores the computational aspects of network information systems as embodied by the World Wide Web (WWW). Topics include languages for document design, programming languages for executable content, scripting languages, design of WWW based human/computer interfaces, client/server network architecture models, high level network protocols (e.g., http), WWW network resource discovery and network security issues.

Students in this course will be expected to complete a substantial software project (e.g., Java based user interface, HTML/CGI based information system, WWW search mechanisms).

Recommended background: CS 2102, CS 2103, or CS 2119; and CS 3013.

CS 4341. INTRODUCTION TO ARTIFICIAL INTELLIGENCE.
Cat. I
This course studies the problem of making computers act in ways which we call "intelligent".

Topics include major theories, tools and applications of artificial intelligence; aspects of knowledge representation; searching and planning; and natural language understanding.

Students will be expected to complete projects which express problems that require search in state spaces and to propose appropriate methods for solving the problems.

Undergraduate credit may not be earned both for this course and for CS 534.

Recommended background: CS 2102 or CS 2103; CS 2223; and CS 3133.

CS 4342. MACHINE LEARNING.
Cat.I
In this course, students will explore both theoretical and practical aspects of machine learning, including algorithms for regression, classification, dimensionality reduction, clustering, and density estimation. Specific topics may include neural networks and deep learning, Bayesian networks and probabilistic graphical models, principal component analysis, k-means clustering, decision trees and random forests, support vector machines, and kernel methods.

Recommended background: Multivariate Calculus (MA 1024 or MA 1034), Linear Algebra (such as MA 2071), Probability (MA 2621 or MA 2631), and Algorithms (CS 2223).

Students may not earn credit for both CS 453X and CS 4342.

Undergraduate credit may not be earned both for this course and for CS 539.

CS 4401. SOFTWARE SECURITY ENGINEERING.
Cat. I
This course provides an introduction to the pitfalls and practices of building secure software applications. Topics will include threat modeling, secure software development, defensive programming, web security, and the interaction between security and usability. The course focuses on the application level with minor attention to operating-system level security; network-level security is not covered. Assignments involve designing and implementing secure software, evaluating designs and systems for security-related flaws, and presentations on security issues or tools. All students will be required to sign a pledge of responsible conduct at the start of the course.

Recommended Background: CS3013 and CS3733. The course assumes nontrivial experience with C and Unix, familiarity with operating systems, filesystems, and databases, and experience with technologies for building web applications (from CS4241 or personal experience).

CS 4404. TOOLS AND TECHNIQUES IN COMPUTER NETWORK SECURITY.
Cat. II
This course introduces students to modern network security concepts, tools, and techniques. The course covers security threats, attacks, and mitigations at the operating-system and network levels (as opposed to the software level). Topics include authentication, authorization, confidentiality, integrity, anonymity, privacy, intrusion detection and response, and cryptographic applications. Students will become familiar with modern security protocols and tools. Assignments will involve using security-testing software to uncover vulnerabilities, network packet analyzers, and existing security applications to create secure network implementations. The course requires enough programming and systems background to understand attacks and use systems tools but does not involve significant programming projects. Assignments and projects will use a Linux base for implementation.

Recommended Background: Knowledge of operating systems (CS 3013 or equivalent) and computer networks (CS 3516 or equivalent). Familiarity with Linux or Unix is essential.

CS 4432. DATABASE SYSTEMS II.
Cat. II
This course concentrates on the study of the internals of database management systems. Topics include principles and theories of physical storage management, advanced query languages, query processing and optimization, index structures for relational databases, transaction processing, concurrency control, distributed databases, and database recovery, security, client server and transaction processing systems. Students may be expected to design and implement software components that make up modern database systems.

Undergraduate credit may not be earned both for this course and CS 542.

Recommended background: CS 3431 and CS 3733.

This course will be offered in 2019-20, and in alternating years thereafter.

CS/DS 4433. BIG DATA MANAGEMENT AND ANALYTICS.
Cat. I
This course introduces the emerging techniques and infrastructures for big data management and analytics including parallel and distributed database systems, map-reduce, Spark, and NO-SQL infrastructures, data stream processing systems, scalable analytics and mining, and cloud-based computing. Query processing and optimization, access methods, and storage layouts developed on these infrastructures will be covered. Students are expected to engage in hands-on projects using one or more of these technologies.

Recommended background: Knowledge in database systems at the level of CS4432, and programming experience are assumed.

CS 4445. DATA MINING AND KNOWLEDGE DISCOVERY IN DATABASES.
Cat. II
This course provides an introduction to Knowledge Discovery in Databases (KDD) and Data Mining. KDD deals with data integration techniques and with the discovery, interpretation, and visualization of patterns in large collections of data. Topics covered in this course include data warehousing and mediation techniques; data mining methods such as rule-based learning, decision trees, association rules, and sequence mining; and data visualization. The work discussed originates in the fields of artificial intelligence, machine learning, statistical data analysis, data visualization, databases, and information retrieval. Several scientific and industrial applications of KDD will be studied.

Recommended background: MA 2611, CS 2223, and CS 3431 or CS 3733.

This course will be offered in 2019-20, and in alternating years thereafter.

CS 4513. DISTRIBUTED COMPUTING SYSTEMS.
Cat. II
This course extends the study of the design and implementation of operating systems begun in CS 3013 to distributed and advanced computer systems.

Topics include principles and theories of resource allocation, file systems, protection schemes, and performance evaluation as they relate to distributed and advanced computer systems.

Students may be expected to design and implement programs that emphasize the concepts of file systems and distributed computing systems using current tools and languages.

Undergraduate credit may not be earned both for this course and for CS 502.

Recommended background: CS 3013, CS 3516, and system programming experience.

This course will be offered in 2019-20, and in alternating years thereafter.

CS 4515. COMPUTER ARCHITECTURE.
Cat. II
This course explores the architectural design of modern computer systems in terms of instruction sets and the organization of processors, controllers, memories, devices, and communication links. Topics include an overview of computer architectures and system components, theoretical foundations, instruction-level and thread-level pipelining, multifunction pipelines, multi-core systems, caching and memory hierarchies, and multi-core and parallel computer organization. Students may be expected to design and implement programs that simulate significant components of modern computer architectures.

Recommended background: CS 2011 or ECE 2049, and CS 3013.

This course will be offered in 2020-21, and in alternating years thereafter.

CS 4516. ADVANCED COMPUTER NETWORKS.
Cat. II
This course provides an in-depth look into computer networks. While repeating some of the areas from CS 3516, the goal is to go deeper into computer networks topics. This in-depth treatment in topics such as routing, congestion control, wireless layer protocols, and physical signaling considerations will require the use of basic queuing theory and probability to provide a more formal treatment of computer networks performance. Other topics covered include LAN and WLAN technologies, mobile wireless networks, sensor networks, optical networks, network security, intrusion detection, and network management. Students will be expected to do more sophisticated network programming than seen in CS 3516 and will conduct laboratory activities involving measuring the performance of modern networking applications running on both wired networks and infrastructure wireless networks.

Undergraduate credit may not be earned both for this course and for CS 513.

Recommended background: CS 3013, CS 3516, and knowledge of probability. The course assumes a familiarity with operating systems including Unix or Linux and significant experience with C/C++.

This course will be offered in 2019-20, and in alternating years thereafter.

CS 4518. MOBILE AND UBIQUITOUS COMPUTING.
Cat. II
The goal of this course is to acquaint students with fundamental concepts and state-of-the-art computer science literature in mobile and ubiquitous computing. Topics to be covered include mobile systems issues, human activity and emotion sensing, location sensing, mobile human-computer interaction, mobile social networking, mobile health, power saving techniques, energy and mobile performance measurement studies, and mobile security.
The course will introduce the programming of mobile devices such as smartphones running the Android operating system.
Recommended background: Proficiency in programming in Java, including classes, inheritance, exceptions, interfaces, and polymorphism (CS 2102 or equivalent).
Students may not earn credit for both CS 403X and CS 4518.

CS 4533. TECHNIQUES OF PROGRAMMING LANGUAGE TRANSLATION.
Cat. II
This course studies the compiling process for high-level languages.
Topics include lexical analysis, syntax analysis, semantic analysis, symbol tables, intermediate languages, optimization, code generation, and run-time systems.
Students will be expected to use compiler tools to implement the front end — and to write a program to implement the back end — of a compiler for a recursive programming language.
Undergraduate credit may not be earned for both this course and for CS 544.
Recommended Background: CS 2102 or CS 2103, and CS 3133.
This course will be offered in 2020-21, and in alternating years thereafter.

CS 4536. PROGRAMMING LANGUAGES.
Cat. II
This course covers the design and implementation of programming languages. Topics include data structures for representing programming languages, implementing control structures (such as functions, recursion, and exceptions), garbage collection, and type systems. Students will be expected to implement several small languages using a functional programming language.
Recommended background: CS 2303, CS 3133, and experience programming in a functional language (as provided by CS 1101 or CS 1102).
Undergraduate credit may not be earned for both this course and CS 536.
This course will be offered in 2019-20, and in alternating years thereafter.

CS 4731. COMPUTER GRAPHICS.
Cat. I
This course studies the use of the computer to model and graphically render two- and three-dimensional structures.
Topics include graphics devices and languages, 2- and 3-D object representations, and various aspects of rendering realistic images.
Students will be expected to implement programs which span all stages of the 3-D graphics pipeline, including clipping, projection, arbitrary viewing, hidden surface removal, and shading.
Undergraduate credit may not be earned both for this course and for CS 543.
Recommended background: CS 2223, CS 2303, and MA 2071.

CS 4732. COMPUTER ANIMATION.
Cat. II
This course provides an in-depth examination of the algorithms, data structures, and techniques used in modeling and rendering dynamic scenes. Topics include animation hardware and software; parametric blending techniques; modeling physical and articulated objects; forward and inverse kinematics; key-frame, procedural, and behavioral animation; and free-form deformation. Students will be expected to develop programs to implement low-level animation algorithms as well as use commercial animation tools to design and produce small to moderate sized animations.
Recommended background: CS 4731.
This course will be offered in 2020-21, and in alternating years thereafter.

CS 4801/ECE 4802. INTRODUCTION TO CRYPTOGRAPHY AND COMMUNICATION SECURITY.
Cat. I
This course provides an introduction to modern cryptography and communication security. It focuses on how cryptographic algorithms and protocols work and *how* to use them. The course covers the concepts of block ciphers and message authentication codes, public key encryption, digital signatures, and key establishment, as well as common examples and uses of such schemes, including the AES, RSA-OAEP, and the Digital Signature Algorithm. Basic cryptanalytic techniques and examples of practical security solutions are explored to understand how to design and evaluate modern security solutions. The course is suited for students interested in cryptography or other security related fields such as trusted computing, network and OS security, or general IT security.
Recommended background: Experience in expressing algorithms in a modern programming language (e.g., ECE 2049 or CS 2301).
Suggested background: Discrete mathematics (CS 2022/MA 2201 or equivalent)

CS 4802/BCB 4002. BIOVISUALIZATION.
Cat. II
This course will use interactive visualization to model and analyze biological information, structures, and processes. Topics will include the fundamental principles, concepts, and techniques of visualization (both scientific and information visualization) and how visualization can be used to study bioinformatics data at the genomic, cellular, molecular, organism, and population levels. Students will be expected to write small to moderate programs to experiment with different visual mappings and data types.
Recommended background: CS 2102 or CS 2103; CS 2223; and one or more biology courses.
This course will be offered in 2020-21, and in alternating years thereafter.

CS 4803/BCB 4003. BIOLOGICAL AND BIOMEDICAL DATABASE MINING.
Cat. II
This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining.
Recommended Background: CS 2102 or CS 2103; CS 2223; MA 2610 or MA 2611; and one or more biology courses.
This course will be offered in 2019-20, and in alternating years thereafter.

DATA SCIENCE

DS 1010. DATA SCIENCE I: INTRODUCTION TO DATA SCIENCE.
Cat. I
This course provides an introduction to the core concepts in Data Science. It covers a broad range of methodologies for working with and making informed decisions based on real-world data. Core topics introduced in this course include basic statistics, data exploration, data cleaning, data visualization, business intelligence, and data analysis. Students will utilize various techniques and tools to explore, understand and visualize real-world data sets from various domains and learn how to communicate data results to decision makers.
Recommended background: None

DS 2010. DATA SCIENCE II: MODELING AND DATA ANALYSIS.
Cat. I
This course focuses on model- and data-driven approaches in Data Science. It covers methods from applied statistics (regression), optimization, and machine learning to analyze and make predictions and inferences from real-world data sets. Topics introduced in this course include basic statistics (regression), analytics (explanatory and predictive), basics of machine learning (classification and clustering), eigen values and singular matrices, data exploration, data cleaning, data visualization, and business intelligence. Students will utilize various techniques and tools to explore and understand real-world data sets from various domains.
Recommended background: Data science basics equivalent to DS 1010, applied statistics and regression equivalent to MA2611 and MA 2612, and the ability to write computer programs in a scientific language equivalent to a CS programming course at the CS 1000 or CS 2000 level are assumed.

DS 3010. DATA SCIENCE III: COMPUTATIONAL DATA INTELLIGENCE.
Cat. I
This course introduces core methods in Data Science. It covers a broad range of methodologies for working with large and/or high-dimensional data sets to making informed decisions based on real-world data. Core topics introduced in this course include data collection through use cycle, data management of large-scale data, cloud computing, machine learning and deep learning. Students will acquire experience with big data problems through hands-on projects using real-world data sets.

Recommended background: Data science basics equivalent to DS 1010, and data analysis principles and modeling equivalent to DS 2010, knowledge of basic statistics equivalent to (MA 2611 and MA 2612), and the ability to program equivalent to (CS 1004 or CS 1101 or CS 1102) and (CS 2102, CS 2103 or CS 2119), as well as understanding of databases equivalent to (CS 3431 or MIS 3720) are assumed.

DS/CS 4433. BIG DATA MANAGEMENT AND ANALYTICS.
Cat. I
This course introduces the emerging techniques and infrastructures for big data management and analytics including parallel and distributed database systems, map-reduce, Spark, and NO-SQL infrastructures, data stream processing systems, scalable analytics and mining, and cloud-based computing. Query processing and optimization, access methods, and storage layouts developed on these infrastructures will be covered. Students are expected to engage in hands-on projects using one or more of these technologies.

Recommended background: Knowledge in database systems at the level of CS4432, and programming experience are assumed.

ELECTRICAL AND COMPUTER ENGINEERING

The second digit in electrical engineering course numbers is coded as follows:

0 — Circuits
1 — Fields
2 — Electronic Circuits and Systems
3 — Signals and Communication Systems
4 — Available for Future Use
5 — Machines, Power Systems
6 — Professional and Miscellaneous
7 — Projects, Laboratory, Independent Study
8 — Computers
9 — Electronic Devices

NOTE: Courses listed in previous catalogs with "EE" as the prefix and the same course number as below are considered to be the SAME COURSE.

ECE 1799. FRONTIERS AND CURRENT ISSUES OF ELECTRICAL AND COMPUTER ENGINEERING.
Cat. I (1/6 unit semester course, spread out evenly over A and B terms)
This is a seminar-based course intended for First Year students seeking to understand the breadth of activities, career choices and technology that are considered to comprise Electrical and Computer Engineering. Students considering ECE as a major, both those who are "decided" as well as those who are "undecided" should enroll in ECE 1799. The class meets once a week during the fall semester (A & B terms).

Note: There are no "recommended" or "suggested" courses for this description.

ECE 2010. INTRODUCTION TO ELECTRICAL AND COMPUTER ENGINEERING.
Cat. I
The objective of this course is to introduce students to the broad field of electrical and computer engineering within the context of real world applications. This course is designed for first-year students who are considering ECE as a possible major or for non-ECE students fulfilling an out-of-major degree requirement.

The course will introduce basic electrical circuit theory as well as analog and digital signal processing methods currently used to solve a variety of engineering design problems in areas such as entertainment and networking media, robotics, renewable energy and biomedical applications. Laboratory experiments based on these applications are used to reinforce basic concepts and develop laboratory skills, as well as to provide system-level understanding. Circuit and system simulation analysis tools are also introduced and emphasized.

Topics: Basic concepts of AC/DC and Digital electrical circuits, power, linear circuit simulation and analysis, op-amp circuits, transducers, feedback, circuit equivalents and system models, first order transients, the description of sinusoidal signals and system response, analog/digital conversion, basic digital logic gates and combinatorial circuits.

Recommended Background: high school physics, and MA 1022 (concurrent).

ECE 2019. SENSORS, CIRCUITS, AND SYSTEMS.
Cat. I
This course investigates commonly used sensors such as resistive temperature sensors, capacitive touch sensors, and inductive motion sensors and actuators. Numerous applications are presented to motivate coverage of fundamental operating principles of circuit elements such as resistors, capacitors, and inductors; model the signals produced by these sensors; and analyze the circuits and systems used to amplify and process these signals. After a review of Kirchhoff 's current and voltage laws, fundamental analysis techniques such as Thevenin and Norton's theorems and the superposition principle are used to model and analyze sensors, circuits, and systems. Concepts from analysis of linear, time-invariant continuous-time signals and systems are introduced as necessary, including Fourier series and characterization of systems such as filters in both the frequency domain (bandwidth, transfer function) and time domain (rise time, step response). Capacitance, inductance and mutual inductance are explored as energy storage elements, including consideration of resonance and energy losses in power systems. Concepts will be reinforced with the use of laboratory exercises and computer simulation.

Recommended background: ECE 2010, MA 1024 (or equivalent), PH 1120/21 and MA 2051 (concurrent).

Note: Students who have received credit for ECE 2111 may not receive credit for ECE 2019.

ECE 2029. INTRODUCTION TO DIGITAL CIRCUIT DESIGN.
Cat. I
Digital circuits are the foundation upon which the computers, cell phones, and calculators we use every day are built. This course explores these foundations by using modern digital design techniques to design, implement and test digital circuits ranging in complexity from basic logic gates to state machines that perform useful functions like calculations, counting, timing, and a host of other applications. Students will learn modern design techniques, using a hardware description language (HDL) such as Verilog to design, simulate and implement logic systems consisting of basic gates, adders, multiplexers, latches, and counters. The function and operation of programmable logic devices, such as field programmable gate arrays (FPGAs), will be described and discussed in terms of how an HDL logic design is mapped and implemented. Experiments involving the design of combinational and sequential circuits will provide students a hands-on introduction to basic digital electrical engineering concepts and the skills needed to gain more advanced skills. In the laboratory, students will construct, troubleshoot, and test the digital circuits that they have developed using a hardware description language. These custom logic designs will be implemented using FPGAs and validated using test equipment.

Topics: Number representations, Boolean algebra, design and simplification of combinational circuits, arithmetic circuits, analysis and design of sequential circuits, and synchronous state machines.

Lab exercises: Design, analysis and construction of combinational and sequential circuits; use of hardware description languages to implement, test, and verify digital circuits; function and operation of FPGAs.

Recommended background: Introductory Electrical and Computer Engineering concepts covered in a course such as ECE 2010 or RBE 1001, and MA 1022.

Note: Students who have received credit for ECE 2022 may not receive credit for ECE 2029.

ECE 2049. EMBEDDED COMPUTING IN ENGINEERING DESIGN.
Cat. I
Embedded computers are literally everywhere in modern life. On any given day we interact with and depend on dozens of small computers to make coffee, run cell phones, take pictures, play music play, control elevators, manage the emissions and antilock brakes in our automobile, control a home security system, and so on. Using popular everyday devices as case studies, students in this course are introduced to the unique computing and design challenges posed by embedded systems. Students will then solve real-world design problems using small, resource constrained (time/memory/power) computing platforms. The hardware and software structure of modern embedded devices and basic interactions between embedded computers and the physical world will also be covered in lecture and as part of laboratory experiments. In the laboratory, emphasis is placed on interfacing embedded processors with common sensors and devices (e.g. temperature sensors, keypads, LCD display, SPI ports, pulse

width modulated motor controller outputs) while developing the skills needed to use embedded processors in systems design. This course is also appropriate for RBE and other engineering and CS students interested in learning about embedded system theory and design.

Topics: Number/data representations, embedded system design using C, microprocessor and microcontroller architecture, program development and debugging tools for a small target processor, hardware/software dependencies, use of memory mapped peripherals, design of event driven software, time and resource management, applications case studies.

Lab Exercises: Students will solve commonly encountered embedded processing problems to implement useful systems. Starting with a requirements list students will use the knowledge gained during the lectures to implement solutions to problems which explore topics such as user interfaces and interfacing with the physical world, logic flow, and timing and time constrained programming. Exercises will be performed on microcontroller and/or microprocessor based embedded systems using cross platform development tools appropriate to the target platform.

Recommended Background: ECE 2010 or equivalent knowledge in basic circuits, devices and analysis; and C language programming (CS 2301 or equivalent)

Suggested Background: ECE 2029 or equivalent knowledge of digital logic, logic signals and logic operations;

Note: Students who have received credit for ECE 2801 may not receive credit for ECE 2049.

ECE 2112. ELECTROMAGNETIC FIELDS.
Cat. I
The object of this course is a comprehensive treatment of electromagnetic engineering principles covering the entire application spectrum from static to dynamic field phenomena.

The starting point will be the basic electric and magnetic field definitions of Coulomb and Biot-Savart leading to Gauss's and Ampere's laws. They form the foundation of electro- and magnetostatics fields. Students will examine capacitive and inductive systems and relate them to lumped element circuit models. By introducing temporal and spatial magnetic flux variations, Faraday's law is established. The engineering implications of this law are investigated in terms of transformer and motor actions. Incorporation of the displacement current density into Ampere's law and combining it with Faraday's law will then culminate in the complete set of Maxwell's field equations. As a result of these equations, students will develop the concept of wave propagation in the time and frequency domain with practical applications such as wireless communication, radar, Global Positioning Systems, and microwave circuits.

Recommended background: ECE 2019.

ECE 2201. MICROELECTRONIC CIRCUITS I.
Cat. I
This course is the first of a two-course sequence in electronic circuit design. It begins with a substantive treatment of the fundamental behavior of semiconductor materials and moves on to the semiconductor diode, the bipolar transistor, and the field-effect transistor. Laboratory exercises are provided to reinforce the theory of operation of these devices. Numerous circuit applications are considered, including: power supplies, transistor amplifiers, and FET switches.

Topics include: the pn junction, diode operation, transducers, rectification, voltage regulation, limiting and clamping circuits, transistor operation, biasing, small-signal and large-signal models, transistors amplifiers, and switching applications.

Recommended background: ECE 2019.

ECE 2305. INTRODUCTION TO COMMUNICATIONS AND NETWORKS.
Cat. I
This course provides an introduction to the broad area of communications and networking, providing the context and fundamental knowledge appropriate for all electrical and computer engineers, as well as for further study in this area. The course is organized as a systems approach to communications and networking. Topics include key concepts and terminology (delay, loss, throughput, bandwidth, etc.), types of transmission media, addressing, switching, routing, networking principles and architectures, networking protocols, regulatory and applications issues.

Recommended background: ECE 2010.

ECE 2311. CONTINUOUS-TIME SIGNAL AND SYSTEM ANALYSIS.
Cat. I
This course provides an introduction to time and frequency domain analysis of continuous time signals and linear systems. Topics include signal characterization and operations; singularity functions; impulse response and convolution; Fourier series; the Fourier transform and its applications; frequency-domain characterization of linear, time-invariant systems such as filters; and the Laplace transform and its applications.

Recommended background: MA 2051, ECE 2019, and a prior course in computer programming such as CS 2301 or CS 1101/2/4.

ECE 2312. DISCRETE-TIME SIGNAL AND SYSTEM ANALYSIS.
Cat. I
This course provides an introduction to the time and frequency domain analysis of discrete-time signals and linear systems. Topics include sampling and quantization, characterization of discrete-time sequences, the discrete-time Fourier transform, the discrete Fourier transform and its applications, the Z transform and its applications, convolution, characterization of FIR and IIR discrete-time systems, and the analysis and design of discrete-time filters. The course will include a focus on applications such as sampling and quantization, audio processing, navigation systems, and communications. Extensive use will be made of simulation tools including Matlab.

Recommended background: MA 2051, ECE 2311, and a prior course in computer programming such as CS 2301 or CS 1101/2/4.

ECE 2799. ELECTRICAL AND COMPUTER ENGINEERING DESIGN.
Cat. I
The goal of this course is to provide experience with the design of a system, component, or process. Basic sciences, mathematics, and engineering sciences are applied to convert resources to meet a stated objective. Fundamental steps of the design process are practiced, including the establishment of objectives and criteria, synthesis, analysis, manufacturability, testing, and evaluation. Student work in small teams and are encouraged to use creativity to solve specific but open-ended problems, and then present their results.

ECE 2799 is strongly recommended for all students as a preparation for the design element of the MQP. It is anticipated that ECE 2799 will be of most benefit to students when taken well in advance of the MQP (late sophomore year or early junior year).

Recommended background: At least three of ECE 2019, ECE 2029, ECE 2049, ECE 2311.

ECE 3012. INTRODUCTION TO CONTROL SYSTEMS ENGINEERING.
Cat. I
This course provides an introduction to the analysis and design of continuous-time control systems. Topics covered in the course include: modeling in the frequency and time domain, characteristics of control systems time response, reduction of multiple subsystems, analysis of systems transient response, stability, steady-state errors, root locus techniques, design of PI, PD, and PID controllers via root locus, frequency response techniques, and design via frequency response. The course will not have a formal laboratory. It will include projects which will require the use of software such as MATLAB, Simulink, or LabVIEW for analysis and design of control systems.

Recommended Background: Ordinary Differential Equations (MA 2051), Sensors, Circuits, and Systems (ECE 2019), and Continuous-time Signal and System Analysis (ECE 2311).

Students may not receive credit for both ES 3011 and ECE 3012.

ECE 3113. INTRODUCTION TO RF CIRCUIT DESIGN.
Cat. I
This course is designed to provide students with the basic principles of radio frequency (RF) circuit design. It concentrates on topics such as designing tuning and matching networks for analog and digital communication, satellite navigation, and radar systems.

After reviewing equivalent circuit representations for RF diodes, transistors, FETs, and their input/output impedance behavior, the course examines the difference between lumped and distributed parameter systems. Characteristics impedance, standing waves, reflection coefficients, insertion loss, and group delay of RF circuits will be explained.

Within the context of Maxwell's theory the course will then focus on the graphical display of the reflection coefficient (Smith Chart) and its importance in designing matching circuits. Students will learn the difference between SPICE and monolithic and microwave integrated circuit analysis, and design (MMICAD) modeling. Biasing and matching networks for single and multistage amplifiers in the 900 to 2,000 MHz range are analyzed and optimized in terms of input/output impedance matching, insertion loss, and groups delays.

Recommended background: ECE 2019, ECE 3204.

Suggested background: ECE 2112.

ECE 3204. MICROELECTRONIC CIRCUITS II.
Cat. I
This course is the second of a two-course sequence in electronic circuit design. More complex circuits are analyzed and the effects of frequency and feedback are considered in detail. The course provides a comprehensive treatment of operational amplifier operation and limitations. The use of Bode plots to describe the amplitude and phase performance of circuits as a function of operating frequency is also presented. In addition, the concepts of analog signal sampling, analog-to-digital conversion and digital-to-analog conversion are presented along with techniques for interfacing analog and digital circuitry. Laboratory exercises are provided to reinforce student facility with the application of these concepts to the design of practical circuits.

Topics include: transducers; differential amplifiers, inverting/non-inverting amplifiers, summers, differentiators, integrators, passive and active filers, the Schmitt trigger, monostable and a-stable oscillators, timers, sample-and-hold circuits, A/D converters, and D/A converters.

Recommended background: Introductory electronic-circuit design and analog-signal analysis as found in ECE 2201 and ECE 2311.

ECE 3308. INTRODUCTION TO WIRELESS NETWORKS.
Cat. I
This course is intended for students interested in obtaining a systems-level perspective of modern wireless networks. It starts with an overall understanding of telecommunication and computer communication networks. Then the fundamental theory of operation of wireless networks as well detailed description of example networks will be covered. Topics included in the course are an overview of computer networks, an overview of wireless network standards and products, radio channel modeling and medium access control, deployment of wireless infrastructures, and examples of voice- and data-oriented wireless networks using TDMA, CDMA, and CSMA access methods.

With extra work, this course can be successfully completed by non-ECE students; basic concepts of radio propagation, transmission, and medium access control will be introduced as needed.

Recommended background: MA 1022 and PH 1120.

Suggested background: ECE 2312 and ECE 2305.

ECE 3311. PRINCIPLES OF COMMUNICATION SYSTEMS.
Cat. I
This course provides an introduction to analog and digital communications systems. The bandpass transmission of analog data is motivated and typical systems are analyzed with respect to bandwidth considerations and implementation techniques. Baseband and passband digital transmission systems are introduced and investigated. Pulse shaping and intersymbol interference criteria are developed in relation to the pulse rate transmission limits of bandlimited channels. Finally, digital carrier systems and line coding are introduced in conjunction with applications to modern modem transmission schemes.

Recommended background: MA 1024 and ECE 2312.

Suggested background: ECE 2305.

ECE 3500. INTRODUCTION TO CONTEMPORARY ELECTRIC POWER SYSTEMS.
Cat. I
This course introduces basic concepts underlying the current and future methods of generation, transmission, storage, and use of electric energy. Beginning with an historical overview of the electric power system that has served well for more than 100 years, the course provides an introduction to the fundamental engineering principles underlying the design and implementation of traditional as well as modern electric power systems. Energy sources including thermal (combustion, nuclear, geothermal), solar, wind, and chemical (fuel cells) are presented, along with the environmental impacts. Concepts of three-phase systems, transmission and distribution of power, economic and regulatory aspects, as well as communications, protection, and control systems are included. Student project work is included.

Recommended background: ECE 2010 or equivalent

Suggested background: ECE 2019 or equivalent

ECE 3501. ELECTRICAL ENERGY CONVERSION.
Cat. I
This course is designed to provide a cohesive presentation of the principles of electric energy conversion for industrial applications and design. The generation, transmission and conversion of electric energy, as well as basic instrumentation and equipment associated with electric energy flow and conversion are analyzed.

Topics: Review of poly-phase circuits. Transducers and instrumentation for power and energy measurements. Rotating machines. Electromechanical transients and stability. Switchgear equipment. Selected laboratory experiments.

Recommended background: ECE 2019.

ECE 3503. POWER ELECTRONICS.
Cat. I
This course is an introduction to analysis and design of power semiconductor circuits used in electric motor drives, control systems, robotics and power supply.

Topics: characteristics of thyristors and power transistors. Steady-state performance and operating characteristics, device rating and protection, commutation, gating circuits, ac voltage controllers, controlled rectifiers, dc/dc converters and dc/ac inverters. Laboratory exercises.

Recommended background: ECE 2019, ECE 2201 or equivalent.

ECE 3829. ADVANCED DIGITAL SYSTEM DESIGN WITH FPGAs.
Cat. I
This course covers the systematic design of advanced digital systems using FPGAs. The emphasis is on top-down design starting with high level models using a hardware description language (such as VHDL or Verilog) as a tool for the design, synthesis, modeling, test bench development, and testing and verification of complete digital systems. These types of systems include the use of embedded soft core processors as well as lower level modules created from custom logic or imported IP blocks. Interfaces will be developed to access devices external to the FPGA such as memory or peripheral communication devices. The integration of tools and design methodologies will be addressed through a discussion of system on a chip (SOC) integration, methodologies, design for performance, and design for test.

Topics: Hardware description languages, system modeling, synthesis, simulation and testing of digital circuits; Design integration to achieve specific system design goals including architecture, planning and integration, and testing; Use of soft core and IP modules to meet specific architecture and design goals. Laboratory exercises: Students will design and implement a complete sophisticated embedded digital system on an FPGA. HDL design of digital systems including lower level components and integration of higher level IP cores, simulating the design with test benches, and synthesizing and implementing these designs with FPGA development boards including interfacing to external devices.

Recommended background: ECE 2029 and ECE 2049

Students who have received credit for ECE 3810 may not receive credit for ECE 3829.

ECE 3849. REAL-TIME EMBEDDED SYSTEMS.
Cat. I
This course continues the embedded systems sequence by expanding on the topics of real-time software and embedded microprocessor system architecture. The software portion of this course focuses on solving real-world problems that require an embedded system to meet strict real-time constraints with limited resources. On the hardware side, this course reviews and expands upon all the major components of an embedded microprocessor system, including the CPU, buses, memory devices and peripheral interfaces. New IO standards and devices are introduced and emphasized as needed to meet system design, IO and performance goals in both the lecture and laboratory portion of the course. Topics: Cross-compiled software development, embedded system debugging, multitasking, real-time scheduling, inter-task communication, software design for deterministic execution time, software performance analysis and optimization, device drivers, CPU architecture and organization, bus interface, memory management unit, memory devices, memory controllers, peripheral interfaces, interrupts and interrupt controllers, direct memory access. Laboratory exercises: Programming real-time applications on an embedded platform running a real-time operating system (RTOS), configuring hardware interfaces to memory and peripherals, bus timing analysis, device drivers.

Recommended background: ECE 2029 and ECE 2049.

ECE/BME 4011. BIOMEDICAL SIGNAL ANALYSIS.
Cat. II
Introduction to biomedical signal processing and analysis. Fundamental techniques to analyze and process signals that originate from biological sources: ECGs, EMGs, EEGs, blood pressure signals, etc. Course integrates physiological knowledge with the information useful for physiologic investigation and medical diagnosis and processing. Biomedical signal characterization, time domain analysis techniques (transfer functions, convolution, auto- and cross-correlation), frequency domain (Fourier analysis), continuous and discrete signals, deterministic and stochastic signal analysis methods. Analog and digital filtering.

Recommended background: ECE 2311, ECE 2312, or equivalent.

This course will be offered in 2020-21, and in alternating years thereafter.

ECE/BME 4023. BIOMEDICAL INSTRUMENTATION DESIGN.
Cat. II
This course builds on the fundamental knowledge of instrumentation and sensors. Lectures cover the principles of designing, building and testing analog instruments to measure and process biomedical signals. The course is intended for students interested in the design and development of electronic bioinstrumentation. Emphasis is placed on developing the student's ability to design a simple medical device to perform real-time physiological measurements.
Recommended background: BME 3012, BME 3013, ECE 2010 and ECE 2019.
This course will be offered in 2020-21, and in alternating years thereafter.

ECE 4305. SOFTWARE-DEFINED RADIO SYSTEMS AND ANALYSIS.
Cat. I
This course provides students with hands-on exposure to the design and implementation of modern digital communication systems using software-defined radio technology. The prototyping and real-time experimentation of these systems via software-defined radio will enable greater flexibility in the assessment of design trade-offs as well as the illustration of "real world" operational behavior. Performance comparisons with quantitative analytical techniques will be conducted in order to reinforce digital communication system design concepts. In addition to laboratory modules, a final course project will synthesize topics covered in class. Course topics include software-defined radio architectures and implementations, digital signaling and data transmission analysis in noise, digital receiver structures (matched filtering, correlation), multicarrier communication techniques, radio frequency spectrum sensing and identification (energy detection, matched filtering), and fundamentals of radio resource management.
Recommended background: ECE 3311, MA 2621, familiarity with Simulink, familiarity with general programming.

ECE 4703. REAL-TIME DIGITAL SIGNAL PROCESSING.
Cat. I
This course provides an introduction to the principles of real-time digital signal processing (DSP). The focus of this course is hands-on development of real-time signal processing algorithms using audio-based DSP kits in a laboratory environment. Basic concepts of DSP systems including sampling and quantization of continuous time signals are discussed. Tradeoffs between fixed-point and floating-point processing are exposed. Real-time considerations are discussed and efficient programming techniques leveraging the pipelined and parallel processing architecture of modern DSPs are developed. Using the audio-based DSP kits, students will implement real-time algorithms for various filtering structures and compare experimental results to theoretical predictions.
Recommended background: ECE 2049, ECE 2312, some prior experience in C programming.
Suggested background: ECE 3311.

ECE 4801. COMPUTER ORGANIZATION AND DESIGN.
Cat. I
This course focuses on the computer organization and architectural design of standalone embedded and high-performance microprocessor systems. This course covers performance metrics, machine level representation of information, the assembly level interface, memory system organization and architecture, computer input/output, instruction set architecture (ISA) design, single cycle and multicycle CPU datapath and controlpath design as well as more advanced level topics such as pipelining, interrupts, cache and memory system design. Special attention will be paid into measuring architectural performance and into improving computer architectures at various levels of the design hierarchy to reach optimal performance. The course will include several hands-on projects and laboratory components where students will be required to perform simulations of CPU designs using architectural simulation tools such as MIPS Simulators and SimpleScalar.
Recommended Background: ECE 3849
Suggested Background: ECE 3829

ECE 4802/CS 4801. INTRODUCTION TO CRYPTOGRAPHY AND COMMUNICATION SECURITY.
Cat. I
This course provides an introduction to modern cryptography and communication security. It focuses on how cryptographic algorithms and protocols work and how to use them. The course covers the concepts of block ciphers and message authentication codes, public key encryption, digital signatures, and key establishment, as well as common examples and uses of such schemes, including the AES, RSA-OAEP, and the Digital Signature Algorithm. Basic cryptanalytic techniques and examples of practical security solutions are explored to understand how to design and evaluate modern security solutions. The course is suited for students interested in cryptography or other security related fields such as trusted computing, network and OS security, or general IT security.
Recommended background: ECE 2049 Embedded Computing in Engineering Design or CS 2301 Systems Programming for Non-Majors or equivalent
Suggested background: CS 2022/MA 2201 Discrete Mathematics

ECE 4902. ANALOG INTEGRATED CIRCUIT DESIGN.
Cat. II
This course introduces students to the design and analysis of analog integrated circuits such as operational amplifiers, phase-locked loops, and analog multipliers. Topics: integrated circuit building blocks: current mirrors and sources, differential amplifiers, voltage references and multipliers, output circuits. Computer-aided simulation of circuits. Layout of integrated circuits. Design and analysis of such circuits as operational amplifiers, phase-locked loops, FM detectors, and analog multipliers. Laboratory exercises.
Recommended background: familiarity with the analysis of linear circuits and with the theory of bipolar and MOSFET transistors. Such skills are typically acquired in ECE 3204.
Suggested background: ECE 4904.
This course will be offered in 2019-20, and in alternating years thereafter.

ECE 4904. SEMICONDUCTOR DEVICES.
Cat. II
The purpose of this course is to introduce students to the physics of semiconductor devices and to show how semiconductor devices operate in typical linear and nonlinear circuit applications. This material complements the electronics sequence of courses and will draw illustrative examples of electronic circuit applications from other courses. Topics: carrier transport processes in semiconductor materials. Carrier lifetime. Theory of p-n junctions. Bipolar transistors internal theory, dc characteristics, charge control, Ebers-Moll relations; high frequency and switching characteristics, hybrid-pi model; n- and p-channel MOSFETS, CMOS.
Recommended background: ECE 2201. Suggested background: ECE 3204 (helpful but not necessary).
Students who have received credit for ECE 3901 may not receive credit for ECE 4904.
This course will be offered in 2020-21, and in alternating years thereafter.

ENGINEERING SCIENCE INTERDISCIPLINARY

ES 1020. INTRODUCTION TO ENGINEERING.
Cat. I
This course is for first year students with an interest in engineering. The course focuses on the design process. Students are introduced to engineering through case studies and reverse engineering activities. Students will learn the steps in the design process and how engineers use this process to create new devices. Teams of students are then assigned a design project that culminates in building and evaluating a prototype of their design. Results of the design project are presented in both oral and written reports. This course does not require any prior engineering background.
Note: This course can be used towards the Engineering Science and Design distribution requirement in IE and ME.

ES 1310. INTRODUCTION TO COMPUTER AIDED DESIGN.
Cat. I
This introduction course in engineering graphical communications and design provides a solid background for all engineering disciplines. The ability to visualize, create and apply proper design intent and industry standards for simple parts, assemblies and drawings is a necessity for anyone in a technology environment. Computer Aided Design software is used as a tool to create 2D & 3D sketches, 3D parts, 3D assemblies and 2D drawings per an industry standard. Multiview and pictorial graphics techniques are integrated with ANSI standards for dimensioning and tolerances, sectioning, and generating detailed engineering drawings. Emphasis is placed on relating drawings to the required manufacturing processes. The design process and aids to creativity are combined with graphics procedures to incorporate functional design requirements in the geometric model. No prior engineering graphics or software knowledge is assumed.

ES 2001. INTRODUCTION TO MATERIALS SCIENCE.
Cat. I
This beginning course provides important background for all science and engineering disciplines regarding the capabilities and limitations of materials in our everyday lives. Students are introduced to the fundamental theme of materials science-- structure-property-processing relationships—in metals, ceramics, and plastics. Aspects of material structure range from the atomic to microstructural and macroscopic scales. In turn, these structural features determine the properties of materials. In particular, this course investigates connections between structure and mechanical properties, and how working and thermal treatments may transform structure and thus alter material properties. This knowledge is then applied to material selection decisions.
Recommended background: prior knowledge of college-level chemistry.

ES 2501. INTRODUCTION TO STATIC SYSTEMS.
Cat. I
This is an introductory course in the engineering mechanics sequence that serves as a foundation for other courses in mechanical engineering. The course covers general two- and three-dimensional force and couple systems, distributed loads, resultant forces, moments of forces, free body diagrams, equilibrium of particles and finite sized bodies. Specific topics include friction, trusses, shear forces, bodies subjected to distributed loads, bending moments in beams, and first and second moments of plane areas.
Recommended background: Differential (MA 1021) and integral (MA 1022) calculus, vector algebra (MA 1023), and double and triple integration (MA 1024).

ES 2502. STRESS ANALYSIS.
Cat. I
This is an introductory course that addresses the analysis of basic mechanical and structural elements. Topics include general concepts of stresses, strains, and material properties of common engineering materials. Also covered are two-dimensional stress transformations, principal stresses, Mohr's circle and deformations due to mechanical and thermal effects. Applications are to uniaxially loaded bars, circular shafts under torsion, bending and shearing and deflection of beams, and buckling of columns. Both statically determinate and indeterminate problems are analyzed.
Recommended background; mechanical systems (ES 2501 or equivalent), differential (MA 1021) and integral (MA 1022) calculus, vector algebra (MA 1023), and double and triple integration (MA 1024).

ES 2503. INTRODUCTION TO DYNAMIC SYSTEMS.
Cat. I
Engineers should be able to formulate and solve problems that involve forces that act on bodies which are moving. This course deals with the kinematics and dynamics of particles and rigid bodies which move in a plane.
Topics covered will include: kinematics of particles and rigid bodies, equations of motion, work-energy methods, and impulse and momentum. In this course a basic introduction to mechanical vibration is also discussed. Basic equations will be developed with respect to translating and rotating coordinate systems.
Recommended background: Statics (ES 2501 or CE 2000).

ES 2800. ENVIRONMENTAL IMPACTS OF ENGINEERING DECISIONS.
Cat. II
Engineering decisions can affect the environment on local and global scales. This course will introduce students to concepts that will make them aware of the ramifications of their engineering decisions, and is intended for engineering students of all disciplines. Specific topics the course will cover include: environmental issues, waste minimization, energy conservation, water conservation and reuse, regulations (OSHA, TSCA, RCRA, etc.), lifecycle assessment, risk assessment, sustainability, design for the environment, and environmental impact statements. Energy and mass balances will be applied to activities that impact the environment. Instruction will be provided through lectures, practitioner seminars, and a term project. Intended audience: all engineering majors desiring a general knowledge of the environmental impacts of engineering decisions.
Recommended background: elementary college chemistry; second year students.
This course will be offered in 2020-21, and in alternating years thereafter.

ES 3001. INTRODUCTION TO THERMODYNAMICS.
Cat. I
This course emphasizes system and control volume modeling using conservation of mass and the First and Second Laws of Thermodynamics. Topics include an introduction to heat, work, energy, and power, properties of simple substances, and cycle analysis for power production and refrigeration.
Recommended background: basic physics, (PH 1110, PH 1111) elementary differential and integral calculus (MA 1021, MA 1022) or equivalents.

ES 3002. MASS TRANSFER.
Cat. I
This course introduces the student to the phenomena of diffusion and mass transfer. These occur in processes during which a change in chemical composition of one or more phases occurs. Diffusion and mass transfer can take place in living systems, in the environment, and in chemical processes. This course will show how to handle quantitative calculations involving diffusion and/or mass transfer, including design of process equipment.
Topics may include: fundamentals of diffusional transport, diffusion in thin films; unsteady diffusion; diffusion in solids; convective mass transfer; dispersion; transport in membranes; diffusion with chemical reaction; simultaneous heat and mass transfer; selected mass transfer operations such as absorption, drying, humidification, extraction, crystallization, adsorption, etc.
Recommended background: fundamentals of chemical thermodynamics, fluid flow and heat transfer; ordinary differential equations (MA 2051 or equivalent).

ES 3003. HEAT TRANSFER.
Cat. I
This course presents the fundamentals of heat transfer in the three modes of conduction, convection, and radiation. Topics include steady-state and transient heat conduction, forced external and internal convection, natural convection, heat exchanger analysis, radiation properties, and radiative exchange between surfaces.
Recommended background: knowledge of thermodynamics, fluid mechanics, and ordinary differential equations (ES 3001, ES 3004, and MA 2051) or equivalents.

ES 3004. FLUID MECHANICS.
Cat. I
A study of the fundamental laws of statics, kinematics and dynamics applied to fluid mechanics. The course will include fluid properties, conservation of mass, momentum and energy as applied to real and ideal fluids. Laminar and turbulent flows, fluid resistance and basic boundary layer theory will also be considered.
Recommended background: basic physics, basic differential equations and vectors.

ES 3011. CONTROL ENGINEERING I.
Cat. I
Characteristics of control systems. Mathematical representation of control components and systems. Laplace transforms, transfer functions, block and signal flow diagrams. Transient response analysis. Introduction to the root-locus method and stability analysis. Frequency response techniques including Bode, polar, and Nichols plots.
This sequence of courses in the field of control engineering (ES 3011) is generally available to all juniors and seniors regardless of department. A good background in mathematics is required; familiarity with Laplace transforms, complex variables and matrices is desirable but not mandatory. All students taking Control Engineering I should have an understanding of ordinary differential equations (MA 2051 or equivalent) and basic physics through electricity and magnetism (PH 1120/1121). Control Engineering I may be considered a terminal course, or it may be the first course for those students wishing to do extensive work in this field. Students taking the sequence of two courses will be prepared for graduate work in the field.
Recommended background: Ordinary Differential Equations (MA 2051) and Electricity and Magnestism (PH 1120, PH 1121).
Students may not receive credit for both ES 3011 and ECE 3012.

ES 3323. ADVANCED COMPUTER AIDED DESIGN.
Cat. I
This course is intended to strengthen solid modeling and analysis skills with an emphasis on robust modeling strategies that capture design intent. The use of solid models for applications in mechanical design and engineering analysis is emphasized. Topics include: advanced feature-based modeling, variational design, physical properties, assembly modeling, mechanisms, and other analytical methods in engineering design.
Recommended background: familiarity with drafting standards (ES 1310), mechanical systems (ES 2501 or CE 2000, ES 2503), strength of materials (ES 2502 or CE 2001) and kinematics (ME 3310) is assumed. Additional background in machine design (ME 2300, ME 3320) is helpful.

ES 3501. A PROJECT-BASED INTRODUCTION TO SYSTEMS ENGINEERING.
Cat. I
Systems Engineering is a multifaceted discipline, involving human, organizational, and various technical variables that work together to create complex systems. This course is an introduction and overview of the methods and disciplines that systems engineers use to define and develop systems, with a particular focus on capstone projects. The course will include specific integrated examples, projects, and team building exercises to aid in understanding and appreciating fundamental principles. Topics covered will include: Introduction to Systems Engineering; Requirements Development; Functional Analysis; System Design; Integration, Verification and Validation; Trade Studies and Metrics; Modeling and Simulation; Risk Management; and Technical Planning and Management.
Recommended background: Third or fourth year standing as an undergraduate student, preferably in engineering or science, or permission of the instructor.

FIRE PROTECTION ENGINEERING

FP 3070. FUNDAMENTALS OF FIRESAFETY ANALYSIS.
Cat. I
This course introduces students of different technical disciplines to analytical methods and techniques to address problems of fire, explosions, or hazardous incidents. Emphasis will be placed on understanding the physical concepts of the problem and their interactions. Quantification will adapt existing procedures to appropriate levels of theoretical and empirical methods in the field of fire science and engineering. Computer applications will be incorporated.
Recommended background: mathematics through differential equations; engineering science; fluid mechanics.

FP 3080. INTRODUCTION TO BUILDING FIRES SAFETY SYSTEM DESIGN.
Cat. I
This course introduces principles and applications of building fire safety design. Topics include the interaction between fire, the building, and building occupants; systems that are used to detect, suppress, and control the spread of fire; and systems that facilitate the safe evacuation of occupants during fire. Building code requirements and engineering methods for analysis and design of building fire safety systems will be explored.
Recommended background: Thermodynamics.
This course will be offered in 2020-21, and in alternating years thereafter.

Graduate Fire Protection Engineering Courses of Interest to Undergraduates

FP 520. FIRE MODELING.
(Prerequisite: FP 521 or special permission of the instructor.) Modeling of compartment fire behavior is studied through the use and application of two types of models: zone and field. The field model studied is FDS. The zone model studied is a student developed model. Focus on in-depth understanding of each of these models is the primary objective in terms of needed input, equations solved, interpretation of output and limitations. A working student model is required for successful completion of the course. Basic computational ability is assumed. Basic numerical methods are used and can be learned during the course via independent study. The zone model studied is a student developed model.

FP 521. FIRE DYNAMICS I.
(Prerequisites: Undergraduate chemistry, thermodynamics [or physical chemistry], fluid mechanics and heat transfer.) This course introduces students to fundamentals of fire and combustion and is intended to serve as the first exposure to fire dynamics phenomena. The course includes fundamental topics in fire and combustion such as thermodynamics of combustion, fire chemistry, premixed and diffusion flames, solid burning, ignition, plumes, heat release rate curves, and flame spread. These topics are then used to develop the basis for introducing compartment fire behavior, pre- and post- flashover conditions and zone modeling. Basic computational ability is assumed. Basic numerical methods are used and can be learned during the course via independent study.

FP 553. FIRE PROTECTION SYSTEMS.
(Prerequisites: Undergraduate courses in chemistry, fluid mechanics and either thermodynamics or physical chemistry.) This course provides an introduction to automatically activated fire suppression and detection systems. A general overview is presented of relevant physical and chemical phenomena and commonly used hardware in automatic sprinkler, gaseous agent, foam and dry chemical systems. Typical contemporary installations and current installation and approval standards are reviewed.

FP 554. ADVANCED FIRE SUPPRESSION.
Advanced topics in suppression systems analysis and design are discussed with an aim toward developing a performance based understanding of suppression technology. Automatic sprinkler systems are covered from the standpoint of predicting actuation times, reviewing numerical methods for hydraulic analyses of pipe flow networks and understanding the phenomenology involved in water spray suppression. Special suppression systems are covered from the standpoint of two phase and non-Newtonian pipe flow and simulations of suppression agent discharge and mixing in an enclosure.

FP 555. DETECTION, ALARM AND SMOKE CONTROL.
(Prerequisites: FP 553 and FP 521, which can be taken concurrently.)
Principles of fire detection and using flame, heat and smoke detector technology are described. Fire alarm technology and the electrical interface with fire/smoke detectors are reviewed in the context of contemporary equipment and installation standards. Smoke control systems based on buoyancy and HVAC principles are studied in the context of building smoke control for survivability and safe egress.

FP 570. BUILDING FIRESAFETY I.
This course focuses on the presentation of qualitative and quantitative means for firesafety analysis in buildings. Fire test methods, fire and building codes and standards of practice are reviewed in the context of a systematic review of firesafety in proposed and existing structures.

FP 571. PERFORMANCE-BASED DESIGN.
(Prerequisites: FP 553, FP 521 and FP 570 or special permission of instructor.) This course covers practical applications of fire protection engineering principles to the design of buildings. Both compartmented and non-compartmented buildings will be designed for criteria of life safety, property protection, continuity of operations, operational management and cost. Modern analytical tools as well as traditional codes and standards are utilized. Interaction with architects, code officials and an awareness of other factors in the building design process are incorporated through exercises and a design studio.

FP 572. FAILURE ANALYSIS.
Development of fire investigation and reconstruction as a basis for evaluating, and improving firesafety design. Accident investigation theory and failure analysis techniques such as fault trees and event sequences are presented. Fire dynamics and computer modeling are applied to assess possible fire scenarios and the effectiveness of fire protection measures. The products liability aspects of failure analysis are presented. Topics include products liability law, use of standard test methods, warnings and safe product design. Application of course materials is developed through projects involving actual case studies.

FP 573. INDUSTRIAL FIRE PROTECTION.
(Prerequisites: FP 553, FP 521 or special permission of instructor.) Principles of fire dynamics, heat transfer and thermodynamics are combined with a general knowledge of automatic detection and suppression systems to analyze fire protection requirements for generic industrial hazards. Topics covered include safe separation distances, plant layout, hazard isolation, smoke control, warehouse storage and flammable liquid processing and storage. Historic industrial fires influencing current practice on these topics are also discussed.

FP 575. EXPLOSION PROTECTION.
Principles of combustion explosions are taught along with explosion hazard and protection applications. Topics include a review of flammability limit concentrations for flammable gases and dusts; thermochemical equilibrium calculations of adiabatic closed vessel deflagration pressures and detonation pressures and velocities; pressure development as a function of time for closed vessels and vented enclosures; the current status of explosion suppression technology; and vapor cloud explosion hazards.

FP 580. SPECIAL PROBLEMS
Individual or group studies on any topic relating to fire protection may be selected by the student and approved by the faculty member who supervises the work. Examples include Business Practices, Combustion, People in Fires, Fire Dynamics II, Fire and Materials, Forensic Techniques, and Complex Decision Making.

FP 581. SEMINAR.
Reports on current advances in the various branches of fire protection.

FP 587. FIRE SCIENCE LABORATORY.
(Prerequisite: FP 521.) This course provides overall instruction and hands-on experience with fire science related experimental measurement techniques. The objective is to expose students to laboratory-scale fire experiments, standard fire tests and state-of-the-art measurement techniques. The Lateral Ignition and Flame Transport (LIFT) apparatus, state-of-the-art smoke detection systems, closed-up flashpoint tests and gas analyzers are among the existing laboratory apparatus. Fire related measurement techniques for temperature, pressure, flow and velocity, gas species and heat fluxes, infrared thermometry, Laser Doppler Velocimetry (LVD) and Laser Induced Fluorescence (LIF) will be reviewed.

FP 590. M.S.THESIS
Research study at the M.S. level.

FP 690. PH.D. DISSERTATION.

HUMANITIES AND ARTS

ARABIC (AB)

AB 1531. ELEMENTARY ARABIC I.
Cat. I
An intensive course to introduce the Arabic language to students with no background in Arabic. Oral language acquisition will stress structures and vocabulary required for basic communicative tasks. Emphasis will be on grammar, vocabulary, and writing system. Cultural aspects of Arabic-speaking countries introduced through course material.

This course is closed to native speakers of Arabic and heritage speakers except with written permission from the instructor.

AB 1532. ELEMENTARY ARABIC II.
Cat. I
Continuation of AB 1531. Oral language acquisition will stress structures and vocabulary required for basic communicative tasks. Emphasis will be on grammar, vocabulary, and writing system. Cultural aspects of Arabic-speaking countries introduced through course material.

This course is closed to native speakers of Arabic and heritage speakers except with written permission from the instructor.

Recommended background: AB 1531.

AB 1533. ELEMENTARY ARABIC III.
Cat. I
Continuation of AB 1532. Oral language acquisition will stress structures and vocabulary required for basic communicative tasks. Emphasis will be on grammar, vocabulary, and writing system. Cultural aspects of Arabic-speaking countries introduced through course material.

This course is closed to native speakers of Arabic and heritage speakers except with written permission from the instructor.

Recommended background: AB 1532.

ART HISTORY/ARCHITECTURE (AR)

AR 1100. ESSENTIALS OF ART.
Cat. I
This course provides an introduction to the basic principles of two and three-dimensional visual organization. The course focuses on graphic expression, idea development, and visual literacy. Students will be expected to master basic rendering skills, perspective drawing, concept art, and storyboarding through traditional and/or computer-based tools.

AR 1101. DIGITAL IMAGING AND COMPUTER ART.
Cat. I
This course focuses on the methods, procedures and techniques of creating and manipulating images through electronic and digital means. Students will develop an understanding of image alteration. Topics may include color theory, displays, modeling, shading, and visual perception.

Recommended background: AR 1100.

AR 1111. INTRODUCTION TO ART HISTORY.
Cat. I
How do we understand a work of art? Through readings and the study of objects at the Worcester Art Museum, the student will survey the major developments in world art and be introduced to various critical perspectives in art history. Students will learn how art historians work with primary materials and formulate arguments. No previous knowledge of art is required. (Formerly HU 1014.)

AR/IMGD 2101. 3D MODELING I.
Cat. I
3D modeling is concerned with how to render created forms in a virtual environment. This course covers 3D modeling applications in video game development, film production, product design and fine art. Topics may include creating and armature, modeling organic and hard surfaces and sculpting using traditional techniques applied to a 3D model. Students will create works suitable for presentation in professional quality portfolio.

Recommended background: AR1100 and AR1101.

AR 2111. MODERN ART.
Cat. I
The successive phases of modern art, especially painting, are examined in light of the late-19th-century break with the 600-year old tradition of representation.

Topics covered include: non-objective art and abstraction—theory and practice, primitivism in modern art, surrealism and the irrational, the impact of photography on modern painting, cubism and collage, regionalism and abstract expressionism as American art forms, Pop art and popular culture, and the problem of concept versus representation in art. (Formerly AR 2300.)

AR 2114. MODERN ARCHITECTURE IN THE AMERICAN ERA, 1750-2001 AND BEYOND.
Cat. I
This course studies, in a non-technical way, America's buildings and places, in the context of world architecture in modern times. The history of American architecture was shaped by the forces that shaped America, from its political emergence in the eighteenth century to the post-9/11 era. These forces include dreams of social and spiritual perfection; a tight and conflicted relation with nature; and the rise and spread of industrial capitalism. The same forces created the Modern Movement in architecture. How are modernism and American architecture interrelated? Illustrated lectures, films, and tours of Worcester architecture explore the question, while training students in the methods of architectural history and criticism.

Students who have taken AR 2113, Topics in 19th- and 20th-Century Architecture, since the 2000-2001 academic year MAY NOT take AR 2114 for credit.

AR 2115. TOPICS IN ARCHITECTURE SINCE 1960.
Cat. I
This course offers a detailed overview of the history of architecture between the consolidation of modern architecture in standard architectural practice and the present period of pluralism. Topics covered will include: modernism and its critique in the developing world; Louis I. Kahn's and Robert Venturi's critiques of modernist architecture culture; the High-Tech movement; utopian alternatives to the modernist city; the return of pre-modern urbanism; Critical Regionalism; the rise of Postmodernism 1970-80; the developer-led architectural boom of the 1980s; "Deconstructivism" and critical dissolution of rationalist form; the introduction of CAD in architectural design and its impact on the "blob architecture" of Frank Gehry and others; the development of global models of architectural practice; sustainable architecture and urbanism; global developments in other, related design fields and their consumer culture.

Recommended background: AR 2114.

AR 2202. FIGURE DRAWING.
Cat. I
The focus of this course is in study of representational figure drawing. This course will cover drawing techniques, applied to study from a live model. Topics covered will be sight size measurement, study of form and light, copying from master drawings and applying these lessons to weekly sessions with a live model. Each class will feature a demonstration on the topic followed by individual critique and study.

Recommended Background: AR 1100.

AR/IMGD 2222. 2D ANIMATION I.
Cat. I
2D Animation I teaches students how to draw, pose, breakdown and in-between characters for 2D animation, focusing on weight, balance, timing, and movement to achieve well-structured and fluid animation. Lectures and projects are conducted to train students in the twelve classical animation principles using digital 2D media. Projects and lectures are designed to practice the fundamentals of traditional frame-by-frame and hand-drawn character animation.

Recommended background: Basic knowledge of figure drawing (AR 2202) and digital art software (AR 1101) is recommended.

AR 2301. GRAPHIC DESIGN.
Cat. I
This course introduces design principles and their application to create effective forms of graphic communication. The students will learn the fundamentals of visual communication and will work on projects to analyze, organize, and solve design problems. Topics may include: the design process; figure/ground; shape; dynamic balance; Gestalt principles; typography; layout and composition; color; production and presentation in digital formats.

AR/IMGD 2333. 3D ANIMATION I.
Cat. I
3D Animation I teaches students how to use 3D animation software to apply classical animation principles into 3D work. Lectures focus on creating organic and compelling character animation through body mechanics, weight, and dynamic posing in addition to exposing students to learning how to think about character acting and staging within a 3D environment.
Recommended background: Basic knowledge digital art software (AR 1101) is recommended.
Suggested background: Basic knowledge of animation (IMGD/AR 2222).

AR 2401. VIDEO PRODUCTION.
Cat. I
This course will introduce students to concepts and techniques for live action digital filmmaking. Topics will include constructing a visual narrative, principles of cinematography, visual and audio editing, working with actors, and the stylistic elements of various genres of filmmaking.
Recommended background: Basic knowledge of the history and theory of film (HU 2251 or equivalent).

AR/IMGD 2700. DIGITAL PAINTING.
Cat. I
This course covers painting techniques as applied to texturing a 3D asset or illustration/conceptual art. Topics include are color theory, study of form, lighting, applying traditional painting ideas to the digital format, character design, generation of ideas and a history of digital painting. Each class features a demonstration on the topic followed by individual critique and study. Students work towards a final project that may be suitable for an Art portfolio.
Recommended Background: AR 1101 (Digital imaging and Computer Art); AR 2202 (Figure Drawing)

AR/IMGD 2740. 3D ENVIRONMENTAL MODELING.
Cat. II
The objective of this course is to teach students how to create 3D environments and props for use in digital models, simulations, games, or animation. The course will examine different types of architecture used in 3D spaces. The students will learn how to create historical and fictional interior and exterior environments; to design, model, texture, and render in high details; and to import their creation into an engine for testing. Topics may include space, human scale, set design, surface texturing, and basic camera animation. Students may not receive credit for IMGD/AR 2740 and IMGD/AR 205X.
Recommended Background: Basic 3D modeling skills (AR 1101)
This course will be offered in 2020-21, and in alternating years thereafter.

AR 2750. TOPICS IN STUDIO ART.
Cat. III
Specialty subjects are offered using the research and creative expertise of the department faculty. Content and format varies to suit the interest and needs of the faculty and students. Courses are defined through the registrar and may be repeated for different topics covered. Students may not receive additional credit for taking this course more than once with the same title.
Recommended background: AR 1100

AR/IMGD 3101. 3D MODELING II.
Cat. I
This course will build upon the skills learned in 3D MODELING with studies in life drawing/anatomy study and application towards completed character models. Students will create high resolution sculpts for real time game environments and animation. Topics covered will be character design as it applies to 3D MODELING, creating realistic design sculpts and incorporating them into a game environment as well as the study of anatomy as it applies to organic modeling.
Recommended Background: AR 1101, IMGD/AR 2101, AR 2202

AR 3112. MODERNISM, MASS CULTURE, AND THE AVANT-GARDE.
Cat. I
What is the role of art to be in the modern world? Can art be a vehicle for social change, or should art be a self-critical discipline that pursues primarily aesthetic ends? What is the relationship between art and mass culture? Using primary sources, this course focuses on some of the theorists and artistic trends since the mid-nineteenth century that have sought to resolve this dilemma. These include: Ruskin, Morris and the Arts and Crafts Movement; Art for Art's Sake; the German Werkbund and the Bauhaus; American industrial design.

AR/ID 3150. LIGHT, VISION AND UNDERSTANDING.
Cat. II
By using material from the sciences and the humanities, this course examines the ways in which ideas of knowledge and of human nature have been fashioned. The specific topics include physical theories about light, biological and psychological theories of visual perception, and artistic theories and practices concerned with representation. The mixing of material from different academic disciplines is deliberate, and meant to counter the notion that human pursuits are "naturally" arranged in the neat packages found in the modern university. The course draws upon the physical and social sciences, and the humanities, to examine how those fields relate to one another, and how they produce knowledge and self-knowledge. Cultural as well as disciplinary factors are assessed in this process.
Light, Vision and Understanding is conducted as a seminar. The diverse collection of reading materials includes a number of primary texts in different fields. In addition, the students keep a journal in which they record the results of numerous individual observations and experiments concerning light and visual perception. The course can fit into several Humanities and Arts topic areas as well as serve as a starting point for an IQP. There are no specific requirements for this course, although some knowledge of college-level physics, as well an acquaintance with the visual arts, is helpful.
This course will be offered in 2020-21, and in alternating years thereafter.

AR/IMGD 3200. INTERACTIVE ELECTRONIC ARTS.
Cat. I
This course introduces students to techniques and processes for the creation of real-time, interactive works of art. Students learn to use electronic sensors and other tools for audio, graphics, and video processing, as well as design customized software interfaces to create interactive artworks that respond to users and their environment. The course also introduces students to the work of significant contemporary arts practitioners as well as their historical precedents, with a special emphasis on inter-media works that bridge visual art, music composition, and the performing arts. Topics may include electronic musical instruments and performance interfaces, computer vision, VJing, electronically-augmented dance, controller hacking, wired clothing, networked collaboration and mobile media, and algorithmic and generative art.
Recommended Background: Animation (AR/IMGD 2101 or equivalent), and exposure to digital audio or music and introductory programming.

AR/IMGD 3222. 2D ANIMATION II.
Cat. I
This course will build upon the techniques learned in IMGD/AR 2222. Students will learn to apply the animation principles to character animation. Students are taught how to tell a compelling, character-driven story through a focus on character acting techniques such as body language, lip syncing, facial animation, and micro expressions. Additional topics covered may include sprites for games, biped and quadruped animation, and 2D animation pipelines. Students will create animated sequences that are intended to serve a narrative structure for games and other media.
Recommended background: Knowledge of digital 2D animation techniques and classical animation principles (IMGD/AR 2222).

AR/IMGD 3333. 3D ANIMATION II.
Cat. I
This course will build upon the techniques learned in IMGD/AR 2333. Students will learn to apply the animation principles with a focus on character acting and cinematic animation. Students are taught how to tell a compelling, character-driven story through a focus on acting techniques such as body language, lip syncing, facial animation, and micro expressions whilst incorporating digital cinematography techniques. Additional topics covered may include creating 3D simulations for hair and cloth, biped and quadruped animation, and 3D animation pipelines. Students will create animated sequences that are intended to serve a narrative structure for games and other media.
Recommended background: Knowledge of digital 3D animation techniques and classical animation principles (IMGD/AR 2333).

AR/IMGD 3700. CONCEPT ART AND CREATIVE ILLUSTRATION.
Cat. I
This course covers drawing as it applies to concept art and illustration. The course begins with study of a human model and representational drawing. Following this, students work on drawing from the mind and applying the lessons learned from the figure drawing to creating concept art and illustration. Topics covered are shape recognition and recalling, inventing from the mind, creative starters, study of form and light, visual composition and developing a personal approach, working with individual strengths to create a compelling visual design. Students create a series of concept art exercises and apply these skills towards a personal project of their own.
Recommended Background: AR 2202 (Figure Drawing); IMGD/AR 2700 (Digital Painting)

CHINESE (CN)

CN 1541. ELEMENTARY CHINESE I.
Cat. I
An intensive course to introduce the Chinese language (Mandarin) to students with no background in Chinese. Emphasis will be on learning the foundations of the sound system through pinyin and acquiring familiarity with tones. Oral language acquisition will stress structures and vocabulary required for basic communicative tasks. Cultural aspects of China introduced through course material.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 1542. ELEMENTARY CHINESE II.
Cat. I
Continuation of CN 1541 for non-native, non-heritage speakers. Emphasis on oral communication and vocabulary acquisition continues. Basics of writing system introduced.
Recommended background: CN 1541.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 1543. ELEMENTARY CHINESE III.
Cat. I
Continuation of CN 1542 Mandarin Chinese. Primary emphasis is on conversational skills, with increased character introduction. Recognition of the most-commonly-used Chinese characters will be required by term end.
Recommended background: CN 1542.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 2541. INTERMEDIATE CHINESE I.
Cat. I
Continuation of CN 1542. Course will focus on practical conversations and recognition of Chinese characters, with greater emphasis placed on reading and writing.
Recommended background: CN 1543.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 2542. INTERMEDIATE CHINESE II.
Cat. I
This course will build on intermediate Chinese conversational patterns. Class time will focus on dialogue and mastery of grammatical constructions, as well as character recognition and reading ability. Conversational drills, audio recordings, video, and group interaction will enhance classroom learning.
Recommended background: CN 2541 Intermediate Chinese I or the equivalent.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 2543. INTERMEDIATE CHINESE III.
Cat. I
Continuation of CN 2542. This course continues to build on students' Chinese conversational skills with a focus on dialogue and mastery of grammatical constructions, as well as character recognition and reading ability. Conversational drills, audio recordings, video, and group interaction will enhance classroom learning.
Recommended background: CN 2542 or the equivalent.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 2544. INTERMEDIATE CHINESE IV.
Cat. I
Continuation of CN 2543. Students continue to build their conversational skills through more complex dialogue and more complicated grammatical constructions. Character recognition and reading ability become more central to class assignments. Conversational drills, audio recordings, video, and group interaction will enhance classroom learning.
Recommended background: CN 2543 or equivalent.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 3541. ADVANCED INTERMEDIATE CHINESE I.
Cat. 1
This course focuses on increasingly sophisticated conversational patterns as well as acquiring the vocabulary necessary for reading texts. Emphasis is on developing active skills to move students to a high-intermediate level of proficiency in reading, writing, listening, and speaking, with continued attention on grammar, phrases, sentence patterns, and character recognition.
Recommended background: CN 2544 or the equivalent.
This course is closed to native speakers of Chinese and heritage speakers except with written permission from the instructor.

CN 3542. ADVANCED INTERMEDIATE CHINESE II.
Cat. I
This course builds on advanced intermediate Chinese skills, focusing on both conversational patterns and reading/writing. Class time will focus on dialogue and mastery of increasingly complex grammatical constructions, with emphasis on character recognition and production for reading and writing. Emphasis will be placed on integrating materials in real-world applications. Not open to native or heritage speakers without written permission of instructor. Recommended background: CN 3541 Advanced Intermediate Chinese I or equivalent.
Students may not receive credit for both CN 3542 and CN 354X.

CN 3543. ADVANCED INTERMEDIATE CHINESE III.
Cat. I
This course continues to build on students' advanced intermediate Chinese skills with increasing emphasis on reading and writing. Writing assignments will be geared towards expressing more complex topics in Chinese that are related to cultural phenomena in contemporary Chinese societies. Not open to native or heritage speakers without written permission of instructor. Recommended background: CN 3542 Advanced Intermediate Chinese II or equivalent.
Students may not receive credit for both CN 3543 and CN 355X.

ENGLISH (EN)

EN 1221. INTRODUCTION TO DRAMA: THEATRE ON THE PAGE AND ON THE STAGE.
Cat. I
This introductory course will give the student an understanding of the forms of drama, the styles of theatre performance and production, and the emergence of new forms and styles. Research and writing projects, and performance activities will offer the student experience in the theory and practice studied in the course.

EN 1222. SHAKESPEARE IN THE AGE OF ELIZABETH.
Cat. I
This course is an introduction to Shakespeare, his theatre, and some important concepts of his world. Students will have the opportunity to sample representative Shakespearean tragedies, comedies, and histories. In addition to class discussions and scene work, students will be able to enhance their readings by analyzing video recordings of the plays.

EN 1242. INTRODUCTION TO ENGLISH POETRY.
Cat. I
This course surveys the poems of our language. From the Anglo-Saxon poems to the popular verse of Tennyson, the songs and the poets are legion: Chaucer, Raleigh, Spenser, Marlowe, Shakespeare, Jonson, Donne, Herrick, Milton, Blake, Wordsworth, Coleridge, Byron, Keats, Tennyson, Browning, and Hopkins. The England that nourished these writers will be viewed through their ballads, lyrics, sonnets, epigrams, and epics. "Not marble nor the gilded monuments of princes shall outlive this powerful rhyme."

EN 1251. INTRODUCTION TO LITERATURE.
Cat. I
This course introduces the student to a variety of critical perspectives necessary to an understanding and appreciation of the major forms, or genres, of literary expression (e.g., novel, short story, poetry, drama, and essay). Writing and class discussion will be integral parts of this course.

EN 1257. INTRODUCTION TO AFRICAN AMERICAN LITERATURE AND CULTURE.
Cat. II
This course examines the formation and history of the African American literary tradition from slave narratives to contemporary forms in black popular culture. The course will explore some genres of African American writing and their relation to American literature and to black cultural expression.
This course will be offered in 2020-21, and in alternating years thereafter.

EN 2219. CREATIVE WRITING.
Cat. I
This foundational course in creative writing aims to help students develop or improve the skills of written expression, emphasizing presentation and discussion of original work. Offerings may include generally themed courses covering multiple genres of interest or more specialized workshops in single genres of focus such as fiction, poetry, playwriting, nonfiction, memoir, or short prose forms.

EN 2221. AMERICAN DRAMA.
Cat. I
An investigation into the development of American drama from its beginnings to the present. The history of the emergence of the legitimate theatre in this country will be followed by reading important plays, including the works of O'Neill, Williams, Mamet, Norman, Henley, and others. Discussion of the growth of regional theatres and their importance to the continuation of theatre as a serious and non-profit art form will be included in the course. The student will investigate the importance of theatre practice in the evolution of the dramatic literature of the country.

EN 2222. INTRODUCTION TO TECHNICAL THEATRE.
Cat. I
This course introduces students to a variety of technical theatre disciplines, including scenic, lights, sound, props, costumes and more. Each week, students will focus on different technical elements through a combination of lectures, demonstrations, and hands on workshops. Students will demonstrate their learning through various projects and involvement in the current term production.

EN 2225. THE LITERATURE OF SIN.
Cat. II
This course begins with selections from John Milton's provocative version of Adam and Eve's original sin in *Paradise Lost.* Focusing on Milton, John Donne and others, we will examine the theme of sin—political, religious, and sexual—in early modern literature. The events of the English Reformation profoundly influenced these writers, and their personal struggles against societal institutions have greatly influenced subsequent literary expressions of rage and rebellion. Students will also be reading texts by contemporary writers such as David Mamet which address the theme of sin in the modern city.
This course will be offered in 2020-21, and in alternating years thereafter.

EN 2226. INFECTED SHAKESPEARE: VENEREAL DISEASE, MADNESS, PLAGUE.
Cat. II
With his many references to syphilis, Bubonic Plague, mental illness, and other serious afflictions, Shakespeare illuminates the harsh reality of living in 16th and 17th-century England. This course explores Shakespeare through the historical lens of early modern medical practice. Students will study plays such as *Hamlet, Richard III,* and *The Winter's Tale* alongside accounts by surgeons, doctors, midwives, and others who diagnosed, dissected, and (sometimes) cured. We will also pay close attention to the superstitions, misinformation, and downright strange treatments included in some of these accounts. Through creative and expository writing, students will analyze the impact of disease on Shakespeare's writing. This course is intended for students interested in any one of the following: drama, English literature, the history of medicine, biology, other fields of life sciences.
This course will be offered in 2019-20, and in alternating years thereafter.

EN 2234. MODERN AMERICAN NOVEL.
Cat. II
Selected works of fiction which appeared after World War I will be the focus of this course. Ernest Hemingway, William Faulkner, or other authors of the early modern period will be studied, but significant attention will also be given to contemporary novelists, such as Thomas Pynchon, Philip K. Dick, and Toni Morrison. The cultural context and philosophical assumptions of the novels will be studied as well as their form and technique.
This course will be offered in 2019-20, and in alternating years thereafter.

EN 2237. LITERATURE AND THE ENVIRONMENT.
Cat. II
This course will examine the many ways in which dramatists, essayists, filmmakers, novelists, and poets have articulated ecological and environmental concerns. Topics to be discussed may include changing attitudes towards terms like 'nature' and 'wilderness', the effects of technology on the environment, issues of conservation and sustainability, the dynamics of population growth, the treatment of animals, the production of food, and the presence of the spiritual in nature. Materials will include works by writers such as Wendell Berry, Rachel Carson, Winona LaDuke, Wangari Maathai, Thomas Malthus, Arne Naess, Nicolas Roeg, and Gary Snyder.
This course will be offered in 2020-21, and in alternating years thereafter.

EN 2242. POPULAR FICTION: READING IN INSTALLMENTS.
Cat. I
Students in this course will have the opportunity to read two major masterpieces of English fiction the way they should be read: slowly, carefully, and with relish. Victorian novels are long and the term is short, but by reading novels in the way in which they were read by their original readers—serially—we can experience masterworks by Charles Dickens and George Eliot at comparative leisure, examining one serial installment per class session.

EN 2243. MODERN BRITISH LITERATURE.
Cat. II
A survey of major modern British authors. The works of many of these writers reflect the political, religious, and social issues of the twentieth century. New psychological insights run parallel with experiments in the use of myth, stream of consciousness, and symbolism. Authors studied may include Hardy, Conrad, Owen, Joyce, Lawrence, Woolf, Eliot, Yeats, and Orwell.
This course will be offered in 2019-20, and in alternating years thereafter.

EN 2251. MORAL ISSUES IN THE MODERN NOVEL.
Cat. I
This course focuses on the problem of how to live in the modern world. Emphasis will be placed on the way moral issues evolve within the complications of individual lives, as depicted in fiction. Such authors as Conrad, Kesey, Camus and Ellison show characters struggling with the questions of moral responsibility raised by love, religion, death, money, conformity.

EN 2252. SCIENCE AND SCIENTISTS IN MODERN LITERATURE.
Cat. I
This course surveys the ways in which modern literature has represented science and scientists. Beginning with Mary Shelley's *Frankenstein*, the origin of what Isaac Asimov calls the "damned Frankenstein complex" is examined. More complex presentations of science and scientists occur in twentieth-century works like Brecht's *Galileo*, Huxley's *Brave New World*, and Pirsig's *Zen and the Art of Motorcycle Maintenance.*
The course covers major modern works of fiction and drama, including such literary forms as the play, the novel of ideas, and the utopian novel. Attention is focused on the themes (ideas) in, and the structure of, these works.

EN 2271. AMERICAN LITERYARY HISTORIES.
Cat. I
An investigation into one or more major movements or periods in American literature, focusing on aesthetic formations such as sentimentalism, realism, modernism, or postmodernism, on cultural formations from Transcendentalism and Regionalism through the Lost Generation and the Harlem Renaissance to the Beat Generation and the Native American Renaissance, or delivered through chronological engagements by century, by decade, or by other suitable framings attending to specific communities or sets of writers.
Recommended background: None, though coursework in English (e.g. EN 1251, Introduction to Literature) or any subsequent EN offering will be helpful.

EN 2281. WORLD LITERATURES.

Cat. I

This course will examine literary works from two or more languages, modes, and/or traditions, often connecting these works to other works of expressive culture in the visual and performing arts. Some iterations may turn on a broader survey, others on more particular engagements with wider inflections. Material introduced beyond English will rely on translations but may also include attention to work in the original language. Attention to drama, poetry, and prose from various periods and places will encourage students to connect themes across cultural, formal, and historical divides, utilizing interdisciplinary and theoretical methods in the process of their reading and writing. Students who have previously taken EN 230X cannot take this course for credit.

Recommended background: None, though coursework in English (e.g. EN 1251, Introduction to Literature) or any subsequent EN offering will be helpful, as will courses emphasizing literature and culture offered in AB, CN, GN, and/or SP.

EN 3219. ADVANCED CREATIVE WRITING.

Cat. II

This advanced seminar in creative writing includes sustained attention to the writing of fiction, poetry, and short prose forms among other genres, culminating in final projects (essay, play, poem, story, or some combination thereof) determined by individual interest and in consultation with the instructor. Investigation will also focus on the reading and discussion of exemplary works across genres, with an emphasis on contemporary practice. In the process, regular writing exercises and class visits from established authors will help to create a community of writers grounded in diverse methods.

Suggested background: Introductory level creative writing (EN 2219 (formerly EN 3217) or equivalent).

This course will be offered in 2019-20, and in alternating years thereafter.

EN 3222. FORMS IN WORLD DRAMA.

Cat. II

The study of the major forms of world drama beginning with the Greeks and ending with contemporary works for the stage. Study will focus upon building skills to effectively analyze form and structure through dramatic content, and to create approaches to staging the plays from an informed understanding of the elements of theatrical style. The course will include plays by preeminent playwrights from cultures around the world.

Texts to be studied will vary at each offering.

This course will be offered in 2019-20, and in alternating years thereafter.

EN 3223. FORMS IN MODERN DRAMA.

Cat. II

The study of the forms in modern drama through application of methods of theatre analysis for dramaturgical consideration and staging. Contemporary playwrights studied will include those from around the world whose work has been seen on international stages since the 1950s. Attention to theatre movements that reflect contemporary issues will be included, and producing groups that have operated with textual revision, minimal text, or no texts will be considered.

Texts to be studied will vary at each offering.

This course will be offered in 2020-21, and in alternating years thereafter.

N 3225. SHAKESPEARE IN PERFORMANCE.

Cat. II

This course examines a selection of Shakespeare's plays, specifically addressing issues of performance. We will approach the plays through close reading; in relationship to the historical, cultural, and theatrical context in which they were written and originally produced; through viewing and analysis (film and live performance); and as they have been and can be interpreted for performance. We will explore the relationship between text and performance in a practical way with performance exercises and staging scenes from the plays. We will also consider how production elements (design elements including setting and costumes, casting, direction and performance choices, etc.) create and convey meaning and shape audience response. This course will be offered in 2020-21, and in alternating years thereafter.

Recommended background: Some familiarity with Shakespeare and or/theatre but the course is suitable for anyone with interest in the subject.

EN 3226. STRANGE AND STRANGERS.

Cat. II

This course examines the concept of "strange" and the figure of the "stranger" in a wide range of written and visual texts, from Shakespeare to Albert Camus to the 2017 horror/comedy film Get Out. We will focus on depictions of religious, racial, gendered, and other forms of alienation and otherness, from both an insider's and outsider's perspective.

This course will be offered in 2020-21, and in alternating years thereafter.

EN 3231. SUPERNATURAL LITERATURES.

Cat. II

Take a vacation from the rational, quantifiable, and verifiable, and dip your toes into the ineffable. Unbridled, boundary-bending, and binary-busting, supernatural literature makes space for lived (and undead) experiences outside the mainstream. This course will examine the following questions: How are supernatural stories culturally situated? How is language used in supernatural texts, and when and why does it break down? What can we can learn about the "real" through studying the fantastic? Course content will vary with each offering. Potential areas of focus might include magical realism, the supernatural and folklore, the gothic and gender, the gothic and race, the contemporary ghost story worldwide, and monstrosity and the grotesque.

This course will be offered in 2020-21, and in alternating years thereafter.

EN 3234. MODERN AMERICAN POETRY.

Cat. II

This course examines the poetries and poetics of various modern and contemporary American traditions, focusing on schools and styles from the Modernists and Objectivists through the Black Arts Movement, Confessional Poetry, the New York School, and the San Francisco Renaissance. Attention will also be given to recent innovations in digital poetry, multiethnic poetry, and performance poetry. The course will include poets such as Wallace Stevens, Gwendolyn Brooks, Elizabeth Bishop, A.R. Ammons, Joy Harjo, Jimmy Santiago Baca, Myung Mi Kim, and Saul Williams.

This course will be offered in 2020-21, and in alternating years thereafter.

EN 3238. AMERICAN AUTHORS.

Cat. II

EN faculty with expertise in American literature will select one or more authors to focus on in this course. Examples of such authors are James Baldwin, Octavia Butler, William Faulkner, Toni Morrison, Anne Sexton, and August Wilson. These authors often criticize the political and social status quo, addressing inequities in matters of class, gender, race, and sexuality. The intention is for students to focus on such authors in depth, in preparation for their final seminar or practicum. Faculty offering the course will indicate which authors they intend to present on the HUA website well before student signups, to permit efficient program planning.

Recommended Background: None, though coursework in English (e.g. EN 1251, Introduction to Literature) or any subsequent EN offering will be helpful.

This course will be offered in 2020-21, and in alternating years thereafter.

EN 3248. THE ENGLISH NOVEL.

Cat. I

Participants in this seminar will examine the English novel from its origins in the eighteenth century to its twentieth-century forms, exploring the rich variety of ways a writer may communicate a personal and social vision. The novels treat love, travel, humor, work, adventure, madness, and self-discovery; the novelists may include Fielding, Austen, Dickens, Eliot, Wodehouse, and Woolf.

EN 3271. AMERICAN LITERARY TOPICS.

Cat. I

This course investigates American literature as it relates to a specific theme, issue, controversy, or question. Attention might center upon topics from childhood and friendship to captivity and freedom, and from immigration and labor to law and war, drawing on or even focusing more decidedly upon aspects of identity including but not limited to class, ethnicity, gender, race, religion, and sexuality Authors might extend from nineteenth century exemplars including Emily Dickinson, Herman Melville, Henry David Thoreau, and Walt Whitman to twentieth and twenty-first century figures such as Philip K. Dick, Toni Morrison, Thomas Pynchon, Leslie Marmon Silko, and Richard Wright.

Recommended background: None, though coursework in English (e.g. EN 1251, Introduction to Literature) or any subsequent EN offering will be helpful.

EN ----. DRAMA/THEATRE PERFORMANCES.
TH: ISU
One-sixth unit of credit will be awarded for successful participation on productions. Performance activities currently receiving credit are:
TH 1225Theatre Production Practicum
TH 2225Acting
TH 2227Advanced Acting
TH 2229Advanced Theatre Production Practicum
TH 3225Directing
TH 3227Advanced Directing
TH 3229Dramaturgy
TH 4225Theatre Technology Design
TH 4227Advanced Theatre Technology Design
TH 4229Advanced Dramaturgy
Credit would be given on the condition that the performance takes place in a WPI performance directed or advised by a part- or full-time WPI instructor.
Note: A maximum of four 1/6 units, or a total of two 1/3 units, may be applied toward the five courses, or five one-third units, taken prior to the final Humanities and Arts practicum.

ENGLISH FOR INTERNATIONAL STUDENTS

These courses are recommended for undergraduate non-native speakers of English pursuing their HUA depth and breadth requirement at WPI.

ISE 1800. INTRODUCTION TO ACADEMIC READING AND WRITING FOR NON-NATIVE SPEAKERS OF ENGLISH.
The goal of this course is to provide international students for whom English is not their native language the necessary skills for academic success through reading and writing assignments. Students will focus on developing vocabulary, critical reading, paragraph, and essay writing skills. Emphasis is also given to a review of English grammar through intensive written and oral practice to promote accurate and appropriate language use.
Strongly recommended for first-year international non-native English speakers. Admission determined by Writing Placement or consent of the instructor.

ISE 1801. COMPOSITION FOR NON-NATIVE SPEAKERS OF ENGLISH.
This course is for international students who want to develop their academic writing skills through a sequence of essay assignments, with emphasis on rhetorical and grammatical issues particular to second language learners (ESL). Students will concentrate on producing coherent paragraphs, developing short essays in a variety of rhetorical modes, and improving mechanics (grammar and punctuation) and vocabulary usage. Both personal and academic writing assignments provide practice in the process of writing and revising work for content and form.
Recommended Background: ISE 1800 or equivalent skills (determined by Writing Placement or consent of the instructor).

ISE 1803. ORAL COMMUNICATION FOR NON-NATIVE SPEAKERS OF ENGLISH.
This course focuses on the speaking and listening skills that are necessary in an academic setting. Students practice formal and informal communication skills, including listening comprehension, pronunciation, and conversational and presentation skills. Students are encouraged to practice oral/aural exercises with the class as a whole and in small groups. Class work will build language skills and personal confidence levels.

ISE 2800. COLLEGE WRITING FOR NON-NATIVE SPEAKERS OF ENGLISH.
In this course students will practice analytical reading, writing, and thinking intensively, through a variety of exercises and assignments. Emphasis is placed on using various methods of organization appropriate to the writer's purpose and audience. Students will read and discuss a selection of non-fiction texts; these readings will form the basis for writing assignments in summary, critique, synthesis, and persuasion. The course also stresses the ability to understand, use, and document college-level non-fiction readings as evidence for effectively formulating and accurately supporting a thesis. This course is for international students who have already studied grammar extensively and need to refine the ability to produce acceptable academic English.
Recommended Background: ISE 1801 or equivalent skills (determined by Writing Placement or consent of the instructor).

ISE 2810. LISTENING AND SPEAKING FOR NON_NATIVE SPEAKERS.
Cat. II
This course addresses the academic needs of high-intermediate/advanced non-native English language learners by developing their listening and speaking skills. Students will engage in activities to practice and improve listening skills, and participate in speaking activities to improve comprehensibility through pronunciation improvement.
Recommended background: Oral communication skills (ISE 1803) or equivalent skills.
Note: Students who have taken ISE 281X may not receive credit for this course.
This course will be offered in 2019-2020, and in alternate years thereafter.

ISE 2820. INTENSIVE READING FOR NON-NATIVE SPEAKERS.
Cat. II
The goal of this course is to provide non-native English language students the skills to work with the highest levels of academic and professional reading. Students will develop active and critical reading skills by annotating self-selected academic journal articles, research reports, current news reports and autobiographical literature. Students will create annotated bibliographies, summaries, literature reviews, and critical reaction papers. Students will learn to analyze, synthesize and cite multiple sources when doing academic work. Students will also increase their vocabulary of high-level academic and professional terms.
Recommended background: Composition for Non-native Speakers of English (as covered in ISE 1801) or equivalent skills.
Note: Students who have taken ISE 282X may not receive credit for this course.
This course will be offered in 2019-20, and in alternate years thereafter.

ISE 3800. LOADED LANGUAGE: DISCOURSE AND POWER IN INTERNATIONAL ENGLISH.
Cat. II
This course, for international non-native English speakers, examines how the varieties of this global language can define identity, reflect social structures, and create and maintain power differentials. The course examines discourse, coded language and labels, accents, and strategies for communicating across cultures. We will explore the effects of World Englishes on our own minds, our classroom, our campus, our local community, and the global stage.
Recommended background: Composition for non-native speakers of English (ISE 1801) or equivalent skills.
This course satisfies the Inquiry Seminar requirement.
Note: Students who have taken ISE 380X may not receive credit for this course.
This course will be offered in 2019-2020, and in alternate years thereafter.

GERMAN (GN)

GN 1511. ELEMENTARY GERMAN I.
Cat. I
An intensive language course designed to teach concise expression of ideas in writing and speaking. Basic grammar and significant cultural aspects are introduced through the aid of readings, audio-recordings, video, and oral group interaction. (Formerly GN 2616.)

GN 1512. ELEMENTARY GERMAN II.
Cat. I
A continuation of Elementary German I.
Recommended background: GN 1511.

GN 2511. INTERMEDIATE GERMAN I.
Cat. I
A continuation of Elementary German II, with increased emphasis on oral and written expression. Basic textbook is supplemented by a collection of simple literary texts by the Grimm brothers, Brecht, and Bichsel.
Recommended background: Elementary German II.

GN 2512. INTERMEDIATE GERMAN II.
Cat. I
A continuation of Intermediate German I.
Recommended background: GN 2511.

GN 3511. ADVANCED GERMAN I.
Cat. I
Reading and in-class discussion of a wide variety of contemporary nonfictional and fictional texts. Some video viewing. Weekly brief writing assignments and continued expansion of vocabulary. Weekly vocabulary quiz. Review of grammar and introduction to advanced stylistic problems.
Recommended background: Intermediate German II.

GN 3512. ADVANCED GERMAN II.
Cat. I
A continuation of Advanced German I.
Recommended background: GN 3511.
This course satisfies the Inquiry Practicum requirement.

GN 3513. SURVEY OF GERMAN CIVILIZATION AND CULTURE FROM 1871 TO THE PRESENT.
Cat. II
Conducted entirely in German, the course presents an overview of the development of modern Germany and its culture since the founding of the Second Empire. Background readings in German and English provide the basis for in-class discussion of selected authentic German texts of various kinds: literary works, official documents, political manifestos, letters, and diaries. At least one film will be shown. A number of recurring themes in German culture will inform the content of the course: authoritarianism versus liberalism, idealism versus practicality, private versus public life.
Recommended background: GN 3511 (Advanced German I) and GN 3512 (Advanced German II) or equivalent.
This course satisfies the Inquiry Practicum requirement.
This course will be offered in 2020-21, and in alternating years thereafter.

GN 3514. SEMINAR ON SELECTED TOPICS IN GERMAN LITERATURE.
Cat. II
The content of the seminar will change from time to time. The course will focus either on an author (e.g., Goethe, Heine, Kafka, Gunter Grass, Christa Wolf), a genre (e.g., lyric poetry, drama, narrative prose), a literary movement (e.g., Romanticism, expressionism), or a particular literary problem (e.g., literature and technology, writing and the Holocaust, writing and the city). The seminar will be conducted entirely in German.
Recommended background: GN 3511 (Advanced German I) and GN 3512 (Advanced German II) or equivalent.
This course satisfies the Inquiry Practicum requirement.
This course will be offered in 2019-20, and in alternating years thereafter.

GN 3516. GERMAN FILM.
Cat. II
Since its beginnings in the early 20th century, film has been a powerful medium for popular entertainment as well as a potent expression of society's dreams, fears, and values. Films made in the German-speaking countries are no exceptions, from early expressionist films like The Cabinet of Dr. Caligari through Nazi documentaries like Triumph of the Will to today's feature films such as Grizzly Man and Run Lola Run! Many German directors have achieved international renown. This course, conducted in German, will examine representative German-language films from various perspectives: historical, socio-political, and thematic. Films will be shown in German with English subtitles. The course will include weekly screenings, discussion sessions, and substantial written assignments.
Recommended background: GN3512 or higher.
This course satisfies the Inquiry Practicum requirement.
This course will be offered in 2020-21, and in alternating years thereafter.
Some sections of this course may be offered as Writing Intensive (WI).

HISTORY (HI)

HI 1311. INTRODUCTION TO AMERICAN URBAN HISTORY.
Cat. I
An introduction to the history of the American city as an important phenomenon in itself and as a reflection of national history. The course will take an interdisciplinary approach to study the political, economic, social, and technological patterns that have shaped the growth of urbanization. In addition to reading historical approaches to the study of American urban history, students may also examine appropriate works by sociologists, economists, political scientists and city planners who provide historical perspective.

HI 1312. INTRODUCTION TO AMERICAN SOCIAL HISTORY.
Cat. I
An introduction to the historical study of American society. It addresses two questions: What is social history? and how do social historians work?

HI 1313. THE US AND THE WORLD.
Cat. I.
This reading and discussion course will focus on one or two topics in the history of American foreign relations, usually during the twentieth century, using a variety of primary documents and secondary sources. In recent years the course has focused on U.S. relations with the developing world after World War II, with units on U.S. interventions in Vietnam and Afghanistan. The role of science and technology as part of international development programs is a common theme. This course is excellent preparation for any of WPI's overseas project centers.

HI 1314. INTRODUCTION TO EARLY AMERICAN HISTORY.
Cat. I
An introduction to historical analysis through selected periods or themes in the history of America before the Civil War. A variety of readings will reflect the various ways that historians have attempted to understand the development of America.

HI 1322. INTRODUCTION TO EUROPEAN HISTORY.
Cat. I
This course introduces students to the major currents that have defined modern European History. Themes and topics will vary and may include the philosophical impact of science on modern thought, the development of liberalism and socialism, the crisis of culture in the twentieth century. Students read selections on major episodes in European history and develop their skills in critical thinking, analysis, oral and written argument. No prior knowledge of European history is required.
Some sections of this course may be offered as Writing Intensive (WI).

HI 1330. INTRODUCTION TO THE HISTORY OF SCIENCE AND TECHNOLOGY.
Cat. I
An introduction to the questions, methods and source materials that shape historical studies of science and technology. Sections vary in content and emphases; some may explore the interplay of science and technology across time, while other sections might exclusively develop themes within either the history of science or the history of technology. Students can receive credit only once for HI 1330, 1331, or 1332.

HI 1350. INTRODUCTION TO ENVIRONMENTAL HISTORY.
Cat. I
An introduction to the questions, methods, and source materials that shape historical studies of the environment. This course will explore the influence of nature (i.e., climate, topography, plants, animals, and microorganisms) on human history and the reciprocal influence of people on nature.

HI 2310. TOPICS IN URBAN HISTORY.
Cat. I
This course surveys the interplay of social, economic, demographic, political and cultural forces in shaping the growth, decline and occasional rebirth of urban spaces. Emphasis is placed upon building chronological narratives while attending to the themes, approaches, and sources historians use to reconstruct the tangled infrastructures, stratified economies, segregated spaces and political/administrative structures of cities. Geographies will vary across sections and topics may include Industrializing Cities, Race and Urban Space, Post-Industrial Cities, Urban Technological Infrastructures, or Social Justice in the City.
Students can receive credit only once for HI 2310.

HI 2311. AMERICAN COLONIAL HISTORY.
Cat. I
This course surveys early American history up to the ratification of the Constitution. It considers the tragic interactions among Europeans, Indians, and Africans on the North American continent, the growth and development of English colonies, and the revolt against the Empire that culminated in the creation of the United States of America.

HI 2313. AMERICAN HISTORY, 1789-1877.
Cat. I
This course surveys American history from the Presidency of George Washington to the Civil War and its aftermath. Topics include the rise of American democracy, the emergence of middle-class culture, and the forces that pulled apart the Union and struggled to put it back together.

HI 2314. AMERICAN HISTORY, 1877-1920.
Cat. I
This course surveys the transformation of the United States into an urban and industrial nation. Topics will include changes in the organization of business and labor, immigration and the development of cities, the peripheral role of the South and West in the industrial economy, politics and government in the age of "laissez-faire," and the diverse sources and nature of late 19th- and early 20th-century reform movements.

HI 2315. THE SHAPING OF POST-1920 AMERICA.
Cat. I
This course surveys the major political, social, and economic changes of American history from 1920 to the present. Emphasis will be placed on the Great Depression, the New Deal, suburbanization, McCarthyism, the persistence of poverty, the domestic effects of the Vietnam war, and recent demographic trends.

HI 2316. TWENTIETH CENTURY AMERICAN FOREIGN RELATIONS.
Cat. II
This survey of American diplomatic history begins with World War I and World War II, continues through the early and later Cold War periods, including the Vietnam War, and concludes with an overview of 9/11 and wars in Iraq and Afghanistan. It includes traditional political and diplomatic history, but also broader conceptions of American foreign relations such as culture, economic development, and environment. It addresses the question of American empire, and stresses understanding U.S. policy and actions through a broad international perspective. This course is excellent preparation for any of WPI's overseas project centers.

Some sections of this course may be offered as Writing Intensive (WI).

This course will be offered in 2020-21 and in alternating years thereafter.

HI 2318. TOPICS IN LAW, JUSTICE AND AMERICAN SOCIETY.
Cat. I
This course treats law as a powerful social, economic and political phenomenon that cannot be fully understood apart from its history. Through a focus upon a particular theme and chronology, each section surveys the role of law (constitutional, statutory, regulatory and common) and legal institutions in shaping American society and culture, as well as how the law and its institutions have been shaped by individuals, advocacy groups, and broader social, cultural and political forces. Different sections of this course might explore constitutional law and social change (e.g. civil rights, abortion, and same sex marriage); criminal law and mass incarceration; law and the construction of race; law and gender; or patents, copyrights and intellectual property. This course may be repeated for different topics, and students who took HI 2317 may take HI 2318.

HI 2320. MODERN EUROPEAN HISTORY.
Cat. I
A survey of the major developments in European history from the nineteenth century to the present. The course will focus upon those factors and events that led to the formation of modern European society: revolutions, nationalism, industrialization, world wars, the Cold War, the creation of the European Union. No prior knowledge of European history is required. Especially appropriate for students interested in WPI's global Project Centers in Europe.

Students may not receive credit for HI 2320 and HI 2322.

HI 2324. THE BRITISH EMPIRE.
Cat. I
This course provides a survey of the British Empire from the 18th century to the present. Topics include the formation of a multinational British state; slavery, sugar, and empire; rebellion in the Americas; settlement of Australia and New Zealand; imperial expansion and resistance in India, China and Southern Africa; industrialization and global trade; cultural dimensions of the colonial experience; gender and empire; world wars and decolonization; and reconfigurations of a global Britain. Especially appropriate for students interested in projects centers located in Britain or the former British Empire.

No prior knowledge required.

HI 2328. HISTORY OF REVOLUTIONS IN THE TWENTIETH CENTURY.
Cat. II
A survey of some of the most important revolutionary movements of the twentieth century. We may consider topics such as racial, nationalist, feminist and non-violent revolutionary ideologies, communist revolution, the "green" revolution and cultural revolution. No prior knowledge of the history of revolutions is expected.

This course will be offered in 2019-20, and in alternating years thereafter.

HI 2335. TOPICS IN THE HISTORY OF AMERICAN SCIENCE AND TECHNOLOGY.
Cat. I
This course surveys the interplay of science, technology and culture in American national development. Emphasis is placed upon building chronological narratives while attending to the themes, approaches, and sources historians use to explore Americans' enthusiastic but sometimes controversial embrace of science and technology. Chronologies and themes will vary across sections covering topics such as Science, Technology and Culture in Early America; Science, Technology in Industrializing America; Science and Technology in Post-1945 America; and Technology and Culture in the Rise of Urban America. This course may be repeated for different topics. No prior coursework or background in the history of science and technology is required.

HI 2341. CONTEMPORARY WORLD ISSUES IN HISTORICAL PERSPECTIVE.
Cat. II
This course examines the historical origins of contemporary global crises and political transformations. Students keep abreast of ongoing current events through periodical literature and explore the underlying long-term causes of these events as analyzed by scholarly historical texts. Topics will vary each time the course is taught but may include such topics as the following: The Israeli-Palestinian Conflict, Democratization in Africa, the Developing World and Globalization. No prior knowledge of world history is required.

This course will be offered in 2019-20, and in alternating years thereafter.

HI 2343. EAST ASIA: CHINA AT THE CENTER.
Cat. II
This course will explore two thousand years of Asian participation in an international system, in Asia and with the rest of the world. Whether ruled by Chinese, Turks, Mongols or Manchus, China has been the political and cultural center of East Asia. Understanding the role of this superpower is critical to Asian and world history. The course will focus on themes such as the cosmopolitan experience, the early development and application of 'modern' ideas such as bureaucracy, market economy, and paper currency, and the centrality of religious ideology as a tool in statecraft. No prior knowledge of Asian history is required.

This course will be offered in 2020-21, and in alternating years thereafter.

HI 2350. TOPICS IN THE HISTORY OF SCIENCE.
Cat. I
This course surveys the major developments, research enterprise, controversies and cultural contexts of particular scientific fields while also engaging students in examining the questions, methods and sources that inform the history of science. Sections will vary in topic, focusing on the history of a subset selected from among the following fields: astronomy, cosmology, mathematics, biology, medicine, ecology, evolutionary ideas, the earth sciences, chemistry, physics, or the human sciences. This course may be repeated for different topics. No prior coursework or background in the history of science is required.

HI 2400. TOPICS IN ENVIRONMENTAL HISTORY.
Cat. I
This course surveys the methods and sources that historians adopt to answer three questions central to environmental history: How have constantly changing natural environments shaped the patterns of human life in different regions? How have different human cultures perceived and attached meanings to the natural and built worlds around them, and how have those attitudes shaped their social, economic political, and cultural lives? Finally, how have people altered the world around them, and what have been the consequences of change for natural and human communities alike? Sections will vary in content and emphases alternating between North American, regional, or global approaches. This course may be repeated for different topics. No prior coursework or background in environmental history is required.

HI 2913. CAPITALISM AND ITS DISCONTENTS.
Cat. II
This course focuses on modern capitalism as an economic, social, and cultural formation in global perspective. As capitalism has radically changed the way humans live and work, critics have articulated their various discontents. Topics to be discussed include colonialism, enslavement, industrialization, social movements, automation, climate change, and global inequality. In addition to our readings, students will directly engage with the rich materials on global labor history available at WPI and in Worcester. This course will be offered in 2021-22, and in alternating years thereafter.

HI 2921. TOPICS IN MODERN EUROPEAN HISTORY.
Cat. II
This seminar course examines topics in the cultural, socio-economic and political history of modern Europe. Topics may vary each year among the following: sport and society, film and history, nationalism, gender and class, political economy, environmental history. Readings will include primary and secondary sources. No prior background is required.
Students may not receive credit for both HI 3321 and HI 2921.
This course will be offered in 2019-20 and in alternating years thereafter

HI 2930. TOPICS IN LATIN AMERICAN HISTORY.
Cat. II
This seminar course examines topics in the history of Latin America. It bases those topics on issues in the region that are of critical importance in the present, and it outlines the historical origins and interrogates the historical contexts of those issues. Topics and course materials may vary each year depending on the issues addressed. The broad themes with which these topics may engage include: science, technology, and development; energy, sustainability, and the environment; inequality and social justice; migration and mobility; U.S.-Latin American relations; democracy, populism and nationalism; the Cold War and the post-Cold War global order. Readings will include primary and secondary sources. No prior background is required.
Recommended background: None.
This course will be offered in 2021-22 and in alternating years thereafter.

HI 3312. TOPICS IN AMERICAN SOCIAL HISTORY.
Cat. I
A seminar course on analysis of selected aspects of social organization in American history, with emphasis on the composition and changing societal character of various groups over time, and their relationship to larger social, economic, and political developments. Typical topics include: communities, families, minorities, and women.
Suggested background: Some college-level American history.

HI 3314. THE AMERICAN REVOLUTION.
Cat. I
This seminar course considers the social, political, and intellectual history of the years surrounding American independence, paying particular attention to the changes in society and ideas that shaped the revolt against Great Britain, the winning of independence, and the creation of new political structures that led to the Constitution.

HI 3316. TOPICS IN TWENTIETH-CENTURY U.S. HISTORY.
Cat. II
In this advanced seminar course, students will explore one aspect of twentieth-century U.S. history in more depth. Topics vary each year but may include political movements such as the New Deal or the Civil Rights Movement, an aspect of American foreign policy such as the Cold War, a short time period such as the 1960s, a cultural phenomenon such as consumption, or a geographical focus such as cities or New England. The course will require substantial reading and writing. Suggested background: HI 2314 (American History, 1877-1920), HI 2315 (The Shaping of Post-1920 America), or other American history courses.
This course will be offered in 2019-20, and in alternating years thereafter.

HI 3317. TOPICS IN ENVIRONMENTAL HISTORY.
Cat. II
In this seminar course, students will explore one aspect of U.S. or global environmental history in more depth. Topics vary each year but may include environmental thought, environmental reform movements, comparative environmental movements, natural disasters, the history of ecology, built environments, environmental justice, New England environmental history, or the environmental history of South Asia or another region of the world. The course will require substantial reading and writing. Suggested background: HI 2401 U.S. Environmental History.
This course will be offered in 2020-21, and in alternating years thereafter.

HI 3331. TOPICS IN THE HISTORY OF EUROPEAN SCIENCE AND TECHNOLOGY.
Cat. II
A seminar course on the relationships among science, technology, and society in European culture, examined through a series of case studies. Topics from which the case studies might be drawn include: global scientific expeditions, mapmaking, and European imperialism; the harnessing of science for industrial purposes; the role of the physical sciences in war and international relations; the function of the science advisor in government; the political views and activities of major scientists such as Einstein. Students will use primary sources and recently published historical scholarship to analyze the case studies.
Suggested background: Courses in European history and the history of science and technology.
This course will be offered in 2020-21, and in alternating years thereafter.

HI 3334. TOPICS IN THE HISTORY OF AMERICAN SCIENCE AND TECHNOLOGY.
Cat. I
This seminar will examine a particular issue or theme in the history of American science and technology. Topics will vary from year to year, but may include: technology and the built environment; science, technology and the arts; communications of science and scientific issues with the larger public; technology and scientific illustration; science in popular culture; science and the law; or close examination of episodes in the history of American science and technology such as the American Industrial Revolution; science and technology in the years between the world wars; the Manhattan Project; science and the culture of the Cold War; or science, technology and war in American history. This course will require significant reading and writing.
Suggested background: Some familiarity with history of science or history of technology, and with United States history.

HI 3335. TOPICS IN THE HISTORY OF NON-WESTERN SCIENCE AND TECHNOLOGY.
Cat. II
A seminar course on the relationships among science, technology, and society from cultures outside Europe and North America, examined through a series of case studies. Topics from which the case studies might be drawn include: Chinese medicine and technology; Arabic mathematics, medicine, and astronomy; Indian science and technology (including, for example, metalworking and textile production); Mayan mathematics and astronomy; Polynesian navigation; various indigenous peoples' sustainable subsistence technologies (e.g. African agriculture, Native American land management, aboriginal Australian dreamtime).
Suggested background: Courses in global history and the history of science and technology.
This course will be offered in 2019-20, and in alternating years thereafter.

HI 3341. TOPICS IN IMPERIAL AND POSTCOLONIAL HISTORY.
Cat. II
This seminar course examines topics in the history of European imperialism, colonialism, and the postcolonial aftermath. Topics vary each year among the following: culture and imperialism, the expansion of Europe, the economics of empire, travel and exploration narratives, imperialism in literature and anthropology, decolonization in Asia and Africa, postcolonial studies. Readings will include primary and secondary sources.
This course will be offered in 2020-21, and in alternating years thereafter.

HI 3343. TOPICS IN ASIAN HISTORY.
Cat. I
This seminar course examines topics in the cultural, socio-economic, religious and political history of East Asia. Topics vary each year and may include the following: nationalism and the writing of history, travel and exploration narratives, cross-cultural contact, the role of religion and ideology in political history, development and the environment in Asia, film and history, and the place of minorities and women in Asian societies. Suggested background: previous courses on Asia such as HU 1412, HI 2328, HI 2343, or RE 2724.
Some sections of this course may be offered as Writing Intensive (WI).

HI 3344. PACIFIC WORLDS.
Cat. II
The Pacific Ocean covers a third of our earth's surface. Home to over a thousand languages and thousands of years of rich histories, the Pacific has been and continues to be one of the most diverse regions of cultural, social, economic, and environmental interaction. The course focuses on both local connections to the Pacific, such as the New England whaling industry, and global issues, such as the impact of climate change on Pacific islanders. Other topics to be discussed include the environment, oceanic navigation, arts, colonialism, race, and migration.
This course will be offered in 2020-21, and in alternating years thereafter.

HUMANITIES (HU)

The courses listed below are general humanities courses and are intended to provide conceptual introductions to the major disciplines within the humanities. Students will encounter the basic methods of critical analysis and discussion required for the future investigation of the specific area they choose for their humanities and arts requirement. These courses emphasize patterns of thought, methods of inquiry, appropriate vocabulary, and critical attitudes needed to appreciate most fully various areas in the humanities; they are not intended as surveys or historical overviews. Consequently, in each course the subject matter used to develop and illustrate key concepts and approaches will change regularly. Practice in analytic thinking and writing will be a significant part of each course. The skills generated by these courses will greatly aid students in developing their themes and will be essential for the completion of the Humanities and Arts Requirement.

HU 1222. INTRODUCTION TO MEDICAL HUMANITIES.
Cat. II
How do medicine, disease, health, and healing shape our experience of what it is to be human? What do literature, poetry, popular culture, or religious and spiritual traditions have to do with modern medical practices and institutions? This course provides an introduction to the interdisciplinary field of medical humanities, and its core set of concepts, questions, methodologies, and theoretical frameworks. The course will bring together and familiarize students with work from diverse fields of study, including comparative literature, the visual and performing arts, history of medicine, cultural studies, science and technology studies, anthropology, ethics, and philosophy. Potential course topics include the production and circulation of medical knowledge, embodied experiences of illness and affliction, cross-cultural perspectives on sickness and healing, the social and interpersonal dimensions of illness, illness and medicine in popular culture, and the ways in which humanistic inquiry can enhance and improve contemporary medical practices.
This course will be offered in 2020-21, and in alternating years thereafter.

HU 1411. INTRODUCTION TO AMERICAN STUDIES.
Cat. II
This interdisciplinary course introduces students to a number of basic American Studies methodologies. Emphasis will vary according to the instructor, but usually the course will cover the following: the textual and contextual analysis (at the community, national, and transnational levels) of literary works; the relationships between the literary, performing, and visual arts in a specific time period; the analysis of radio, film, television, and digital media forms at the level of production and reception; the mediation and remediation of cultural, social, and political history.
This course will be offered in 2019-20, and in alternating years thereafter.

HU 1412. INTRODUCTION TO ASIA.
Cat. I
This course will explore Asia through an interdisciplinary approach. We will examine tradition and modernity in some or all of four cultural regions—South Asia (India), East Asia (China), Southeast Asia (Vietnam or Thailand), Inner Asia (Tibet)—and globalization in Japan and/or Hong Kong. We will explore the cultural traditions of these various regions, paying special attention to history, religion, society. We will also consider modern developments in these same regions. The impact of colonialism, nationalism, revolution, industrialization and urbanization on the lives of Asian peoples will be illustrated through films and readings. No prior knowledge of Asian history or culture is expected.

HU 1500. INTRODUCTION TO GENDER, SEXUALITY & WOMEN'S STUDIES.
Cat. II
This foundational course offers an introduction to the interdisciplinary field of gender, sexuality and women's studies. The course fosters critical examination of gender, sexuality and women and asks how the interlocking systems of oppression, including colonialism, racism, sexism, homophobia, transphobia, and ethnocentrism, shape people's lives, and how individuals and groups have worked to resist these oppressions. Potential course topics include histories of gender activism, gender, sexuality and their relationships to the law, religion, reproduction, education, technology, and mental health, globalization and transnational experiences, and the role of popular culture. No prior background is required.
This course will be offered in 2020-21, and in alternating years thereafter.

HU 2222. TOPICS IN MEDICAL HUMANITIES.
Cat. II
Topics in Medical Humanities provides students with opportunities to investigate the human (cultural, religious, historical, philosophical) dimensions of medicine, illness, and healing, from various perspectives in the humanities. Specific themes and topics will vary by section and instructor, and may include both historical and contemporary concerns, consideration of local, national, and/or global scales, and interdisciplinary methods and pedagogies drawn from a range of fields, such as comparative literature, the visual and performing arts, history of medicine, cultural studies, science and technology studies, anthropology, ethics, and philosophy. Students will analyze interactions between human beings and their environments, the production and circulation of medical and psychiatric knowledge, and historical, sociological, artistic, and literary considerations of medicine, health, and healing.
This course will be offered in 2020-21, and in alternating years thereafter.

HU 2251. INTRODUCTION TO FILM STUDIES.
Cat. II
This course provides an introductory window into the history and theory of film, and may cover genres from short films, silent films, animated films, documentary films, and experimental films to historical and literary adaptations, science fiction films, screwball comedies, thrillers, and westerns. In addition, attention may be given to representative directors, significant theories of film, national traditions of filmmaking, and recent convergences between film forms and digital media. Directors covered may include Charlie Chaplin, John Ford, and Alfred Hitchcock. Film theorists covered may include Stanley Cavell, Sergei Eisenstein, and Trinh T. Minh-ha.
This course will be offered in 2020-21 and in alternating years thereafter.
Recommended background: None.

HU 2258: WORLD CINEMAS.
Cat. II
This course will examine works of film from multiple continents, drawing on film criticism and theory and attending to the development of film industries in several different cultural contexts and national traditions. Some iterations may turn on a broader survey, others on more particular engagements with wider inflections. For example, an offering emphasizing African film might attend not only to films made on the African continent but also to films emerging from the African diaspora in the Americas, and an offering emphasizing Italian film would also attend not only to the films made on the Italian peninsula but also to films emerging from the Italian diaspora in Australia and the United States. Recommended background: None, though HU 2251: Introduction to Film Studies will serve as useful preparation.
This course will be offered in 2021-2022, and in alternating years thereafter.

HU 2340. POPULAR CULTURE AND SOCIAL CHANGE IN ASIA.
Cat. II
Godzilla, kung-fu, *anime*, sushi, Hello Kitty, yin and yang, Pokémon, *manga*. All of these have become part of our American lives, but where did they come from and what meaning do they hold as cultural phenomena? In this class we will explore the popular cultures of East Asia to better understand the influences that have shaped the region's contemporary societies. Focus country will be either Japan or China, depending on term offered. Students will study various media of popular culture, such as films, songs, advertisements, video games, *manga, anime*, to explore the changing society of these countries. We will link the individual cultural phenomena studied to both internal and external influences, situating popular culture within transnational currents and exchanges when appropriate. No prior knowledge of Asian history is required for this class.
This course will be offered in 2019-20, and in alternating years thereafter.

HU 2501. STEM-INISM.
Cat. II
The study and practice of STEM-inism centers the equal participation and representation of all social groups in the fields of science, technology, engineering, and math (STEM). In particular, this course highlights the concepts, theories, and practices of feminism into its understanding of STEM-inism as a field of inquiry. This course provides an overview of the history of female and non-binary contributors and contributions to this field of study and practice, ranging from Hypatia to Ada Lovelace to NASA visionary Katherine Johnson to queer and trans STEM visionaries Martine Rothblatt, Joan Roughgarden, and Lynn Conway. This course may also consider the following topics: the gender gap in STEM fields, biases in medical research, sexual harassment, eugenics, reproductive justice, transgender rights, and contemporary social movements. The course will also incorporate a deliberate analysis of intersecting identity categories, including race, class, sexuality, religion, and ability.
This course will be offered in 2020-21, and in alternating years thereafter.

HU 2502. GLOBAL FEMINISMS.
Cat. II
Bringing together transnational, postcolonial, and indigenous feminist and queer lines of thought, this course provides a global perspective on the interdisciplinary field of gender, sexuality, and women's studies. Motivated by the idea that marginalized peoples - including women, those who identify as non-binary, and ethnic, religious, and economic minorities - share common experiences of exclusion and common stories of resistance, this course fosters critical examination of the relationship between gender, sexuality, feminism, colonialism, and racism. It may consider this intersection through case studies from Africa, Asia, Latin America, and the Middle East with particular attention to places that host WPI project centers.
This course will be offered in 2021-22, and in alternating years thereafter.

HU 2900. HUMANITIES AND ARTS PROJECT PREPARATION.
Cat. I (1/6 unit)
This course is required of students accepted to off-campus Humanities and Arts centers and programs. The course introduces students to methods for site-specific research, project-design, and analysis related to humanities and arts study. It also develops HUA disciplinary skills appropriate both to the projects students have selected and to the culture of the project center where they will be working. Students learn to develop project objectives, milestones, and deliverables in their topic areas related to their forthcoming onsite work and expectations. Students make presentations, write an organized project proposal, and develop a deliverable design for reporting their project findings. This course is a pre-requisite for off-campus Humanities and Arts project center study only.
This credit will not count toward the Humanities and Arts requirement.
Recommended background: none.

HU 3900. INQUIRY SEMINAR IN HUMANITIES AND ARTS.
Cat. I
This seminar serves as the culmination for a student's Humanities and Arts Requirement. The seminar provides opportunities for sustained critical inquiry into a focused thematic area. The seminar seeks to help students learn to communicate effectively, to think critically, and to appreciate diverse perspectives in a spirit of openness and cooperation through research, creativity, and investigation. The specific theme of each seminar will vary and will be defined by the instructor. Prior to enrolling in the seminar, a student must have completed five courses in Humanities and Arts, at least two of which must be thematically related and at least one of which must be at the 2000-level or above.

HU 3910. PRACTICUM IN HUMANITIES AND ARTS.
Cat. I
The practicum serves as the culmination for a student's Humanities and Arts Requirement. The practicum provides opportunities for sustained critical inquiry into a focused thematic area. The practicum seeks to help students learn to communicate effectively, to think critically, and to appreciate diverse perspectives in a spirit of openness and cooperation through research, creativity, and investigation. The specific theme of each practicum will vary and will be defined by the instructor. Prior to enrolling in the practicum, a student must have completed five courses in Humanities and Arts, at least two of which must be thematically related and at least one of which must be at the 2000-level or above. Consent of the instructor is required for enrollment.

HU—AAS-50. AMERICAN ANTIQUARIAN SEMINAR.
ISU
Each fall the American Antiquarian Society and five Worcester colleges sponsor a research seminar at the Antiquarian Society library. The seminar is conducted by a scholar familiar with the Society's holdings in early American history, and the seminar topic is related to his or her field of research.
Selection is highly competitive. The ten participating students are chosen by a screening committee made up of representatives of the five participating colleges: Assumption College, Clark University, College of the Holy Cross, WPI, and Worcester State College.
The seminar topic and research methods combine several disciplines, and students from a wide variety of majors have participated successfully in this unique undergraduate opportunity.

INTERNATIONAL AND GLOBAL STUDIES

INTL 1100. INTRODUCTION TO INTERNATIONAL AND GLOBAL STUDIES.
Cat. I
An introduction to the main concepts, tools, fields of study, global problems, and cross-cultural perspectives that comprise international and global studies. No prior background is required. Especially appropriate for students interested in any of WPI's global Project Centers.

INTL 1300. INTRODUCTION TO LATIN AMERICA.
Cat. I
This course reviews the past and present of South America, Central America and the Caribbean through an interdisciplinary approach. It examines historical and contemporary issues related to social mobilization, cultural innovation, political activism, economic development, and environmental sustainability through the critical analysis of books, films, and creative arts from and about the region. It also presents an overview of Latin American relations with other parts of the world through the region's experiences with global culture, migration, imperialism, dependency, and entanglements with the United States. This course is especially appropriate for students who expect to complete their HUA, IQP, and/or MQP at WPI project centers in Latin America. No prior knowledge is expected.
Recommended background: None.

INTL 2100. APPROACHES TO GLOBAL STUDIES.
Cat. I
This course examines the major theoretical and methodological approaches that characterize global studies. Since the end of the Cold War, new forms of transnational integration, interdependence and conflict have been considered examples of globalization. Yet this period is not the first to undergo such transformation, and the "global" is often experienced in disparate ways around the world. This course examines the diverse ways of understanding globalization in the past and present. No prior background is required. Especially appropriate for students interested in any of WPI's global Project Centers.

INTL 2110. GLOBAL JUSTICE.
Cat. II
What is justice during an era of globalization? What are the rights and responsibilities of individuals, groups, nations, or supranational organizations in a world of profound inequalities of wealth or disparities of power? This course takes an interdisciplinary approach to historical, literary, religious, and ethical debates about global justice as well as the political and practical responses by various actors in the global South and North. Themes will vary each time the course is taught and may include globalization and distributive justice, climate justice, migration, citizenship, cosmopolitanism, human rights, ideology, reparations, racial or gender equity, nationalism and internationalism, and global democracy. No prior background required.
Recommended background: None.
This course will be offered in 2020-21, and in alternating years thereafter.

INTL 2310. MODERN LATIN AMERICA.
Cat. II
This course uses interdisciplinary, thematic, and case study approaches in the examination of modern Latin America. It draws from the Latin America's diversity to explore topics in the past and present that are critical for students' development of a more advanced understanding of the region and its residents. The course may include the study of topics such as cultural production, nationalism, urban and rural development, migration, social and racial inequality, democracy, and social justice through the disciplines of history and global studies, literature and creative arts, social sciences, environmental studies, and others. Examples and case studies from the nineteenth, twentieth, and twenty-first centuries will be drawn especially from locations in Latin America where WPI maintains Global Project Centers.
Students may not receive credit for both INTL 221X and INTL 2310.
This course will be offered in 2020-21 and in alternating years thereafter.

INTL 2410. MODERN AFRICA.
Cat. II
This interdisciplinary course takes a thematic approach to modern Africa. Topics and themes will vary each time the course is taught, and may include African kingdoms, the influence of Islam, the legacy of the Atlantic slave trade, imperialism and decolonization, democratization, the politics of language, or African literature and art. Examples and case studies will include locations where

WPI has programs in this diverse and dynamic region. No prior background required.
Students may not receive credit for both INTL 2410 and HU 2441.
Recommended background: None.
This course will be offered in 2021-22, and in alternating years thereafter.

INTL 2420. MIDDLE EAST, NORTH AFRICA AND MEDITERRANEAN.
Cat. I
This interdisciplinary course takes a thematic approach to the Middle East, North Africa and Mediterranean region. Themes and topics will vary each time the course is taught, and may include religion and culture, national, ethnic and linguistic identities, the Mediterranean as a contact zone, U.S. political and economic involvement in the region, postcolonialism, war and conflict, migration, forced displacement and refugees, human rights, religious freedom, popular culture, the politics of Islam and secularism, the regional intersections of Judaism, Christianity, and Islam, representations of Islam and other religions in visual culture, gender and media, and the circulation of U.S. culture. Examples and case studies will include locations where WPI has programs in this diverse and dynamic region. No prior background required.
Recommended background: None.

INTL 2510. CONTEMPORARY EUROPE: UNION AND DISUNION.
Cat. II
This interdisciplinary course takes a thematic approach to contemporary Europe, especially since the establishment of European Union's single market and common currency. Topics and themes will vary each time the course is taught and may include expansion of the EU and Euro, the impact of the free movement of goods, capital, services and people, migration and refugees, populist and nationalist movements, uneven development between regions within Europe, postcolonial relations with other parts of the world, and debates over national heritage and cultural change. Examples and case studies will include locations where WPI has programs in Europe. No prior background is required.
Recommended background: None.
This course will be offered in 2020-21, and in alternating years thereafter.

INTL 2520. RUSSIA READY: LANGUAGE AND CULTURAL CONTEXT.
Cat. II (1/6 unit)
This course will introduce students to the fundamentals of Russian language, current events and culture. Students will be expected to steadily build essential vocabulary, learn basic grammar and forms of address; they will also review major events of Russian history from the rule of Peter the Great to the Russian Revolution and the Soviet era developments - all of which are key to understanding of Russia today. All through the course, students will have assigned media topics ranging from the student life in Russia, to aerospace exploration to agricultural breakthroughs and political turmoil. Materials under study will include Russian language textbooks and grammar guides, current media, and film. This course is appropriate for students interested in all WPI's project centers in Eastern and Central Europe.
This course will be offered in on-line format.
Students may not receive credit for HU 2230 or HU 223X and INTL 2520.

INTL 2910. TOPICS IN GLOBAL STUDIES.
Cat. I
This seminar course takes an interdisciplinary approach to historical and contemporary topics in global studies. Topics vary each year and may include international development, global inequality and justice, global public health, war and terrorism, international organizations and governance, humanitarianism and human rights, travel and tourism, the Anthropocene, climate change. No prior background is required. Especially appropriate for students interested in any of WPI's global Project Centers.

INTL 3050. GLOBAL RE-ENTRY SEMINAR.
Cat. I (1/6 unit)
Global projects are often life-changing and many students want to make sense of their experience and deepen global learning after returning to campus. This course provides opportunities for self-reflection about global experiences, for connecting with peers to share stories, and for translating these experiences into skills and future professional opportunities, which may include internships, scholarships, post-graduate study or employment. Students completing this seminar will have reflected on their global experiences, articulated and identified transferable skills garnered while away, and integrated these reflections into future academic plans, personal aspirations, or career goals.
Recommended background: This course is intended for students who have participated in WPI's global programs, including global IQPs, MQPs, Humanities projects, or exchange programs, either in the US or abroad.

INTL 4100. SENIOR SEMINAR IN INTERNATIONAL AND GLOBAL STUDIES.
Cat. I
In this capstone seminar in International and Global Studies, students will reflect on what they learned in previous global experiences and critically analyze contemporary global issues. The seminar aims to develop habits of lifelong learning as students articulate strategies for translating global experiences and expertise into personal values and professional opportunities in their future careers.

MUSIC (MU)

MU 1511. INTRODUCTION TO MUSIC.
Cat. I.
This course, designed for students who have little or no previous experience in music, will present an approach to the study of music that includes studying some concepts of music theory (rhythms, scales, keys, intervals, harmony). The course will also include a study of some of the great masterpieces though listening, reading, and discussion.
Recommended background: No previous experience is necessary.

MU 1611. FUNDAMENTALS OF MUSIC I.
Cat. I
This course concentrates on basic music theory of the common practice period. If time permits, instruction includes ear training, sight singing, and work on scales and intervals.
Recommended background: basic knowledge of reading music.

MU 2300. FOUNDATIONS OF MUSIC TECHNOLOGY.
Cat. II
This course will present ways to facilitate musicianship through the use of technology. Course topics include an introduction to music notation software, MIDI and audio recording, signal processing, and interactive music system programming. The course will address past, current, and emerging trends in music technology as they relate to facilitating an understanding of musical concepts. Students may not receive credit for both MU 2300 and MU 230X.
Suggested background: a basic understanding of music notation and the fundamentals of music.
This course will be offered in 2020-21, and in alternating years thereafter.

MU/PSY 2501. MUSIC AND MIND.
Cat. I
How are we able to distinguish instruments, timbres and rhythms from the intertwined sonic stream presented by the world? How do we organize these elements in time to create rhythms, melodies, phrases and pieces? How do perception and memory contribute to our understanding and navigation of a musical work? We will explore these questions by considering the cognitive and perceptual processes that shape our musical experience. Topics covered will include event distinction, temporal perception, hierarchical organization, perceptual grouping, expertise, memory and categorization. Psychological Ideas will be musically illustrated through close listening exercises involving a variety of musical works. We will consider how psychological principles are applied to music technologies, such as compression algorithms, mixing methodologies and the field of music information retrieval. We will consider experimental methods that purport to further our understanding of musical experience.
Recommended Background: Fundamentals of Music I and/or Fundamentals of Music II

MU 2611. FUNDAMENTALS OF MUSIC II.
Cat. I
Fundamentals II is a course on music theory at the advanced level beginning with secondary dominants and modulations and working through 19th-century chromatic harmony.

MU 2719. JAZZ HISTORY.
Cat. II
Through an introduction to the musical contributions of Louis Armstrong, Duke Ellington, Charlie Parker, Miles Davis and others, students are exposed to the chronological development of the language of jazz. Each jazz era is examined in detail including the musical and social contexts which helped define it. Participants are expected to build aural skills with the goal of identifying specific historical periods through the recognition of particular musical characteristics. Students examine in depth one artist of their choice.
This course will be offered in 2020-21, and in alternating years thereafter.
[This replaces MU 4623. Credit is not allowed for both MU 4623 and MU 2719.]

MU 2720. MUSIC HISTORY I: MEDIEVAL THROUGH THE BAROQUE.
Cat. II
This course provides a historical survey of Western music from Medieval through Baroque periods with an emphasis on understanding stylistic traits and theoretical concepts of the eras. Topics include Gregorian chant and secular monophony; evolution of musical notation; development of polyphonic music; and vocal and instrumental genres such as mass, motet, madrigal, opera, cantata, sonata, and concerto, among others.
No prior background in music is necessary.
This course will be offered in 2020-21, and in alternating years thereafter.

MU 2721. MUSIC HISTORY II: CLASSICAL TO THE PRESENT.
Cat. I
This course provides a historical survey of Western music from the Classical period to the present with an emphasis on understanding stylistic traits and theoretical concepts of the eras. Topics include the development of genres such as sonata, string quartet, concerto, symphony, symphonic poem, character piece, Lied, and opera; and 20th century trends of impressionism, primitivism, atonality, serialism, minimalism, aleatory music, and electronic music.
No prior background in music is necessary.

MU 2722. HISTORY OF AMERICAN POPULAR MUSIC.
Cat. I
This course will explore the uniqueness of America's popular music and its origins in the music of Africa and the folk music of Europe. Particular emphasis will be given to the origins and history of rock 'n' roll examining its roots in blues and early American popular music. [This replaces MU 4625. Credit is not allowed for both MU 4625 and MU 2722.]

MU 2723. MUSIC COMPOSITION.
Cat. I
This course will investigate the sonic organization of musical works and performances, focusing on fundamental questions of unity and variety. Using a progressive series of composition projects, the class will examine aesthetic issues that are considered in the pragmatic context of the instructions that composers provide to achieve a desired musical result. The class will examine the medium of presentation - whether these instructions are notated in prose, as graphic images, or in symbolic notation. Weekly listening, reading, and composition assignments draw on a broad range of musical styles and intellectual traditions, from various cultures and historical periods.
The class will meet for two weekly sessions of one hour and fifty minutes. Each student will be assigned a performance ensemble. Each performance ensemble will have a weekly two-hour lab. In addition, each student will keep a weekly log (online) of his or her experiences as a composer.

MU 2730. JAZZ THEORY.
Cat. I
This course examines harmonic and melodic relationships as applied to jazz and popular music composition. Students are introduced to a wide range of jazz improvisational performance practices. Topics include compositional forms, harmonic structures, major and minor keys, blues, modal jazz, and re-harmonization techniques. Students are expected to have a basic knowledge of reading music. [This replaces MU 4624. Credit is not allowed for both MU 4624 and MU 2730.]

MU 2801. MAKING MUSIC WITH MACHINES.
Cat. II
This course will explore automatic mechanical (electro)acoustic instruments, the people that design and build them and the music that they make. The subject is inherently interdisciplinary, so activities will engage with historical, musical, and technical matters. The history of automatic mechanical instruments reaches back centuries: we will study past designs so that we can better contextualize modern efforts, which have progressed alongside increasing computational power and machine sensing abilities. We will consider the music that has been composed using such instruments including the works of Anthiel, Nancarrow, Ligeti, Gann, and Metheny. In doing so, we will develop analytical tools required to understand such music and will illuminate relationships between electromechanical capabilities and musical ideas. The technical components of this course will introduce students to principles involved in instrument design, actuators, electronic circuits, microcontrollers, and musical programming environments. We will do all of this with our mind open to the question of how we can design new machines to make new kinds of music.
Recommended Background: Fundamentals of Music I and / or Fundamentals of Music II, experience with programming and electronic circuits is helpful.
This course will be offered in 2020-21, and in alternating years thereafter.

MU 3001. WORLD MUSIC.
Cat. II
This course introduces students to selected musical cultures of the world, e.g., Africa, Asia, the Middle East, and Latin America, from the ethnomusicological perspective by examining their musical styles as well as cultural and social contexts. Students will be expected to read materials in interdisciplinary areas, including musical ethnographies.
No prior background in music is necessary.
This course will be offered in 2019-20, and in alternating years thereafter.

MU 3002. ARRANGING AND ORCHESTRATION.
Cat. I
Students will study specific characteristics of instruments and the voice to enable them to successfully arrange vocal and instrumental music. Students will need to possess a basic knowledge of music theory. Suggested background for this course is MU 1611 (Fundamentals of Music I) or its equivalent.

MU 3614. TOPICS IN MIDI.
Cat. II
This course examines topics in Music Technology in which the application of MIDI and MIDI systems play a significant role. Topics may vary each year among the following areas: sequencing, live performance, composition, and film scoring. Students can take MU 3614 only one time for credit, but a student interested in taking another version can take a second one as an ISU.
Recommended background: MU 1611 (Fundamentals of Music)
This course will be offered in 2020-21, and in alternating years thereafter.

MU 3615. TOPICS IN DIGITAL SOUND.
Cat. II
This course examines topics in Music Technology in which Digital Sound plays a significant role. Topics may vary each year among the following areas: digital editing, audio recording, film scoring, game audio, sound effects, audio production, theatrical sound, and surround sound. Students can take MU 3615 only one time for credit, but a student interested in taking another version can take a second one as an ISU.
Recommended background: MU 1611 (Fundamentals of Music)
This course will be offered in 2020-21, and in alternating years thereafter.

MU 3616. TOPICS IN INTERACTIVE PROGRAMMING.
Cat. II
This course examines topics in Music Technology in which Interactive Programming plays a significant role. Topics may vary each year among the following areas: real time performance controllers, algorithmic composition, interface design, sensor technology, and gesture detection.
Students can take MU 3616 only one time for credit, but a student interested in taking another version can take a second one as an ISU.
Recommended background: MU 1611 (Fundamentals of Music)
This course will be offered in 2020-21, and in alternating years thereafter.

MU 3620. ELECTRONIC MUSIC COMPOSITION.
Cat. II
This course will address concepts of composition through the use of technology. Students will examine existing compositions in electronic music, art music, popular music, film, multimedia, games, and more, and compose new works within these genres. Students will present newly composed works each class and discuss their aesthetic values, musical functions, and technical underpinnings. Students may not receive credit for both MU 3620 and MU 362X.
Suggested background: knowledge of basic musicianship skills such as melody, harmony, and rhythm, as well as familiarity with at least one digital audio workstation or notation software.
This course will be offered in 2020-21, and in alternating years thereafter.

MU 4621. INDEPENDENT INSTRUCTION (LESSONS) IN MUSIC.
ISU
Students electing to complete their Humanities and Arts Requirement in music may, for one of their five courses, undertake 1/3 unit (normally at 1/12 unit per term) of private vocal or instrumental instruction. (Supplemental ensemble work is also strongly recommended.) The student must receive prior approval by a member of the WPI music faculty, and the instruction must be beyond the elementary level. Lessons involve a separate fee. Note that the maximum of 1/3 unit credit for lessons may be earned in addition to 1/3 unit credit for performance (see condition A or B below). Additional work, either in performance or lessons, may be acknowledged on the WPI transcript but will carry no WPI credit. Private lessons: voice, piano, organ, winds, brass, strings, and percussion.

MUSIC ENSEMBLES (MU)

Students who sing or play a traditional band or orchestra instrument at the intermediate level or better may enroll for any of the ensembles listed below. Students will register at the beginning of A term and receive 1/6 unit at the end of B term for participation in both terms. Students may also register at the beginning of C term and receive 1/6 unit at the end of D term for participation in both terms. Students may apply up to 1/3 unit of performing ensembles to the Humanities and Arts course requirement.

MU 2631. GLEE CLUB.
Cat. I
The Glee Club is one of WPI's choral ensembles and the oldest student organization on campus. Glee Club performs many styles and periods of the vast repertoire of music featuring tenor and bass voices. Several times each year the Glee Club and Alden Voices (soprano and alto voices) join forces as the WPI Festival Chorus to perform major works of the repertoire. The Glee Club regularly performs on campus, throughout the Worcester area, and takes international and domestic tours. Rehearsals are held weekly. No audition is required. The course is open to all who are interested and sing in the tenor and bass range.

MU 2632. ALDEN VOICES.
Cat. I
Alden Voices is one of WPI's choral ensembles and also functions as a student organization on campus. Alden Voices performs many styles and periods of the vast repertoire of music featuring soprano and alto voices. Several times each year the Alden Voices and the Glee Club (tenor and bass voices) join forces as the WPI Festival Chorus to perform major works of the repertoire. Alden Voices regularly performs on campus, throughout the Worcester area, and takes international and domestic tours. Rehearsals are held weekly. No audition is required. The course is open to all who are interested and sing in the soprano and alto range.

MU 2633. BRASS ENSEMBLE.
Cat. I
The Brass Ensemble performs frequently on campus and on tour and is open to students who perform on trumpet, trombone, euphonium, French horn, tuba, or tympani. Renaissance antiphonal music is included in the repertoire. Rehearsals are held weekly. Students are expected to perform with the ensemble and to know how to read music. Permission of the instructor is necessary to register.

MU 2634. JAZZ ENSEMBLE.
Cat. I
The Jazz Ensemble performs frequently on campus and on tour and plays jazz arrangements written for a small ensemble with major emphasis on improvisation. Rehearsals are held weekly. Students are expected to perform with the ensemble and to know how to read music. Permission of the instructor is necessary to register.

MU 2635. STAGE BAND.
Cat. I
The Stage Band performs traditional and contemporary big band literature with an emphasis on stylistically appropriate interpretation and performance practice. The ensemble performs frequently on campus and on tour. Rehearsals are held weekly. Students are expected to perform with the ensemble and to know how to read music. Permission of the instructor is necessary to register.

MU 2636. CONCERT BAND.
Cat. I
The Concert Band is a large ensemble that performs several concerts a year as well as on tour. Membership is open to those who play traditional wind, brass or percussion instruments. Rehearsals are held weekly. Students are expected to perform with the ensemble and to know how to read music.

MU 2637. STRING ENSEMBLE.
Cat. I
The String Ensemble performs music for string orchestra both on campus and on tour. Members of the string ensemble also comprise the string section for the full orchestra. Rehearsals are held weekly. Students are expected to perform with the ensemble and to know how to read music.

MU 2638. CHAMBER CHOIR.
Cat. I
The Chamber Choir is WPI's smaller, audition-based, choral ensemble. This ensemble explores specific stylistic techniques as pertains to the music of the Renaissance, Baroque, twentieth century, jazz, and extended vocal techniques (electronic, digital and experimental). The ensemble meets weekly. Students are expected to be of the highest vocal caliber and should possess advanced sight-reading techniques. Open to all who are interested. Permission of the instructor is necessary to register.

PHILOSOPHY (PY)

PY/RE 1731. INTRODUCTION TO PHILOSOPHY AND RELIGION.
Cat. I
This course provides an overview of key concepts, methods and authors in both fields. These introduce the student to the types of reasoning required for the pursuit of in-depth analysis in each discipline.
Emphasis on topics and authors varies with the particular instructor.

PY 2711. EPISTEMOLOGY.
Cat. II
Epistemology is the branch of philosophy inquiring into the nature and conditions of knowledge and truth. Epistemologists ask such questions as: How should we define knowledge? Is knowledge generated by reason or experience? How has knowledge of nature been represented in Western philosophy and science? Is knowledge objective? What constitutes adequate justification for holding a belief? Do attributions of epistemic credibility vary among knowers from different social, cultural, and economic locations? How do power and ideology shape our experiences of the world? Students explore questions such as these and others as they submit their own beliefs about the nature of knowledge to philosophical examination. The course readings and situating context for inquiry will vary each time the course is taught, with each iteration focusing on a particular period or school of philosophical thought. Possible contexts include seventeenth century philosophy or other periods in the history of philosophy, critical theory, pragmatism, analytic philosophy, phenomenology, and feminist philosophy.
Recommended Background: none
This course will be offered in 2020-21, and in alternating years thereafter.

PY 2712. SOCIAL AND POLITICAL PHILOSOPHY.
Cat. II
This course examines metaphysical and moral questions that philosophers have raised about social and political life. Among questions treated might be: What are the grounds, if any, of the obligation of a citizen to obey a sovereign? Are there basic principles of justice by which societies, institutions and practices are rightly evaluated? What is democracy, and how can we tell if an institution or practice is democratic? To what degree do economic institutions put limits on the realization of freedom, democracy and self-determination? Readings might include excerpts from the works of Plato, Hobbes, Locke, Rousseau and Marx, as well as numerous contemporary philosophers.
Suggested background: familiarity with basic concepts in philosophy (as in PY/RE 1731).
This course will be offered in 2019-20, and in alternating years thereafter.

PY 2713. BIOETHICS.
Cat. II
The purpose of this course is to evaluate the social impact of technology in the areas of biology/biotechnology, biomedical engineering and chemistry. The focus of the course will be on the human values in these areas and how they are affected by new technological developments. The course will deal with problems such as human experimentation, behavior control, death, genetic engineering and counseling, abortion, and the allocation of scarce medical resources. These problems will be examined through lectures, discussions and papers.
Suggested background: knowledge of key terms and concepts as given in PY/RE 1731 and PY/RE 2731.
This course will be offered in 2019-20, and in alternating years thereafter.

PY/RE 2716. GENDER, RACE, AND CLASS.
Cat. II
This course examines the meanings of social categories such as gender, race, class, sexuality, ability, nationality, and species. What are the philosophical and religious foundations of the categorizations of beings operative in our contemporary cultures? How do attributions of same and different, normal and abnormal, rational and irrational, human and nonhuman shape social and

political processes of inclusion and exclusion? Are social categories real, constructed, or both? This course focuses primarily on intersectional approaches to oppression and identity that see social categories such as gender, race, and class as mutually constitutive rather than separable. Course readings span a range of philosophical and religious traditions including Continental philosophy, analytic philosophy, Latina/o studies, feminist theory, queer theory, critical race theory, disability studies, and environmental studies. Students may not earn credit for both PY 2716 and RE 2716.

This course will be offered in 2019-20, and in alternating years thereafter.

PY 2717. PHILOSOPHY AND THE ENVIRONMENT.
Cat. I
This course will focus on the following questions:

What is the scope of the current environmental crisis? What does this crisis reveal about the philosophical presuppositions and dominant values of our intellectual worldviews and social institutions? How can existing social theories help explain the environmental crisis? What implications does the crisis have for our sense of personal identity? What moral and spiritual resources can help us respond to it?

Readings will be taken from contemporary and historical philosophers and naturalists.

Suggested background: familiarity with basic concepts in philosophy (as in PY/RE 1731).

PY 2718. EXISTENTIALISM AND PHENOMENOLOGY.
Cat. I
This course focuses on two important movements in nineteenth and twentieth century philosophy, existentialism and phenomenology. Readings might include works by Kierkegaard, Dostoyevsky, Nietzsche, Husserl, Heidegger, Beauvoir, Sartre, Merleau-Ponty, Levinas, and Fanon, as well as contemporary readings by feminist, critical race, and queer theorists working within these traditions. Students will also encounter some of the great works of existentialist fiction and cinema. Themes that may be explored include the relationship between self and other, the tension between freedom and responsibility, the possibility of ethics after World War II, and the problem of ethical and political commitment in an alienating world.

Recommended Background: none

PY 2719. PHILOSOPHY OF SCIENCE.
Cat. I
This course is an in-depth consideration of the meaning, value, and consequences of scientific inquiry. Questions explored may include: Does science yield truth? Are the results of scientific inquiry more a reflection of the workings of the human mind than of those of the external world? Do pivotal scientific concepts like gene, electron, photon, species, and ecosystem point to entities that actually exist? Does the history of science, which includes many refutations of theories once believed to be true, raise questions about whether currently accepted theories should be trusted? By what methods does a scientific community validate knowledge claims and how are these processes affected by social, political, and economic contexts? Does a scientist have a responsibility to conduct morally conscientious research? How does the development of technology affect our spiritual and moral characters? In what ways is science similar to religion and in what ways is it different? The focus of this course may vary each time it is offered from an examination of science in general to an investigation of the foundations of specific branches of science such as physics, biology, environmental science, or social science.

Recommended Background: PY/RE 1731, Introduction to Philosophy and Religion or PY/RE 2731, Introduction to Ethics.

PY/RE 2731. ETHICS.
Cat. I
This course offers a general introduction to modern moral theory. What makes one action wrong, and another right? What are our moral duties towards others? Do moral values change over time, making beliefs about right and wrong simply "relative," or are moral values objective, holding true for all people, everywhere, at all times? Should emotions play a role in ethical deliberation, or should we aspire to be purely rational when engaged in moral thought and action? Is it okay to cheat on an exam, so long as everybody else does it? Do we have a right to use animals in laboratory experiments? Is eating meat ethical? Is it wrong to share a racist or sexist joke? Should abortion be legal? Students will learn how to apply key moral concepts to real-world problems and situations after closely studying several moral theories, including utilitarianism, Kantianism, and feminist care ethics. Other topics covered include moral relativism, psychological hedonism, and ethical egoism.

PY/RE 2732. SUFFERING, HEALING & VALUES.
Cat. II
This course examines medicine, not from a scientific or professional view, but from a specifically humanistic approach. Using essays, films, fiction, poetry and plays, we will aim to make explicit the moral values most deeply held by practitioners in the healing professions. What other kinds of values can get in the way of those most deeply held aims? What are the responsibilities of a medical professional in today's society? What are the sources of those responsibilities? The course will focus both on professional and personal dilemmas and will help students think through some moral problems that are likely to confront them in their professional and personal lives. The class should also help prepare students to navigate through the tough moral issues they are likely to face, either as a medical professional, a citizen, a parent, a child of parents, or as potentially a sick person themselves. This class proposes to grant students the reflective time to read some of the most eloquent authors on suffering, caretaking, and sickness (for example, Oliver Sacks, Jerome Groopman, Susan Sontag, Leo Tolstoy, Virginia Woolf, Tony Kushner, Tracy Kidder, Perri Klass, etc.) and to express their reflections on these resources in effective communication.

Recommended Background: PY/RE 1731 or an introductory level literature course.

This course will be offered in 2020-21, and in alternating years thereafter.

PY 2734. PHILOSOPHY AND SPIRITUALITY.
Cat. II
Spirituality is a philosophical perspective which stresses the role of virtue in happiness and morality; a psychological perspective on emotions and desire; and an essential dimension of religious life. Found in all religions, it is also personally important for the tens of millions who describe themselves as "spiritual but not religious." This course will investigate the many dimensions of spiritual thought and practice, focusing on questions such as: What Similarities/differences exist among the spiritual teachings of traditional religions? What is a spiritual experience, a spiritual lesson, a spiritual life? What is the role of spiritual practices such as yoga, meditation, and prayer? What is the place of spirituality in medicine (e.g.,meditation as treatment for stress), our relation to nature (e.g., the experience of a sunset), and political life (e.g., Gandhi, King, spiritual environmentalism)? Beyond scientific knowledge, technological expertise, and common sense, is there such a thing as wisdom?

Recommended background: PY/RE 1731, Introduction to Philosophy and Religion.

This course will be offered in 2020-21, and in alternating years thereafter.

PY 3711. TOPICS IN PHILOSOPHY.
Cat. I
This course is organized around an advanced or specialized topic in philosophy and provides preparation for HU 3900 Inquiry Seminars in philosophy and religion. Emphasis on topics and authors will vary with instructor, but will typically involve the study of: a particular philosopher (e.g., Plato, Marx, Dewey, Arendt); a particular philosophical tradition (e.g., Pragmatism, Analytic Philosophy, Buddhism, Feminism); a particular philosophical problem or topic (free will, globalization, consciousness, social movement, justice); or a particular philosophical classic (Aristotle's Ethics, Hobbes's The Leviathan, Beauvoir's The Second Sex). The topical theme of the course will be provided as a modified course title in the course description posted online.

Recommended Background: None.

PY 3712. PHILOSOPHY OF RELIGION.
Cat. II
This course will focus on philosophical questions concerning the following topics: the existence and nature of God; the compatibility of God and evil; the nature of religious faith and the relationship between religion, science and ethics; interpretations of the nature of religious language; the philosophically interesting differences between Western and Eastern religions; philosophical critiques of the role of religion in social life. Authors may include: Hume, Kant, Kierkegaard, Buber, Tillich, Daly, Nietzsche and Buddha.

Suggested background: familiarity with basic religious concepts and terms (as in PY/RE 1731).

This course will be offered in 2020-21, and in alternating years thereafter.

RELIGION (RE)

RE/PY 1731. INTRODUCTION TO PHILOSOPHY AND RELIGION.
Cat. I
This course provides an overview of key concepts, methods and authors in both fields. These introduce the student to the types of reasoning required for the pursuit of in-depth analysis in each discipline.
Emphasis on topics and authors varies with the particular instructor.

RE/PY 2716. GENDER, RACE, AND CLASS.
Cat. II
This course examines the meanings of social categories such as gender, race, class, sexuality, ability, nationality, and species. What are the philosophical and religious foundations of the categorizations of beings operative in our contemporary cultures? How do attributions of same and different, normal and abnormal, rational and irrational, human and nonhuman shape social and political processes of inclusion and exclusion? Are social categories real, constructed, or both? This course focuses primarily on intersectional approaches to oppression and identity that see social categories such as gender, race, and class as mutually constitutive rather than separable. Course readings span a range of philosophical and religious traditions including Continental philosophy, analytic philosophy, Latina/o studies, feminist theory, queer theory, critical race theory, disability studies, and environmental studies. Students may not earn credit for both PY 2716 and RE 2716.
This course will be offered in 2019-20, and in alternating years thereafter.

RE 2721. RELIGION AND CULTURE.
Cat. I
The purpose of this course is to examine how the two institutions of religion and culture interact and mutually influence one another. To do this a variety of definitions of religion and culture will be presented as well as an analysis of how religion interacts with such cultural phenomena as economics, politics, the state, war and the basic problem of social change. The purpose of this is to obtain a variety of perspectives on both religion and culture so that one can begin to articulate more clearly the different influences that occur in the development of one's own personal history and the culture in which one lives.
Suggested background: knowledge of key terms and concepts as given in PY/RE 1731.

RE 2722. MODERN PROBLEMS OF BELIEF.
Cat. I
This course examines the ways in which religious problems of meaning have been encountered in the context of the eclipse of religion in Western culture from the Enlightenment to the present. The class emphasizes challenges presented to traditional belief systems by modern thought in areas such as the sciences, psychology, textual criticism, and historical events, as well as some religious responses to those challenges. How do religions respond to the limits of human intellectual capacity, limits of human endurance, and limits of moral comprehension?

RE 2725. RELIGIOUS AND SPIRITUAL TRADITIONS.
Cat. I
The primary aim of this course would be student literacy in global religions. The course examines, from historical, doctrinal, scriptural and/or philosophical perspectives, major world religious and spiritual traditions. Attention will be given to the social context in which these religious traditions developed and will examine their continuing influence. Students taking RE2725 should not receive credit for RE2723 or RE2724, since RE2725 replaces them.
Recommended background: None

RE/PY 2731. ETHICS.
Cat. I
This course offers a general introduction to modern moral theory. What makes one action wrong, and another right? What are our moral duties towards others? Do moral values change over time, making beliefs about right and wrong simply "relative," or are moral values objective, holding true for all people, everywhere, at all times? Should emotions play a role in ethical deliberation, or should we aspire to be purely rational when engaged in moral thought and action? Is it okay to cheat on an exam, so long as everybody else does it? Do we have a right to use animals in laboratory experiments? Is eating meat ethical? Is it wrong to share a racist or sexist joke? Should abortion be legal? Students will learn how to apply key moral concepts to real-world problems and situations after closely studying several moral theories, including utilitarianism, Kantianism, and feminist care ethics. Other topics covered include moral relativism, psychological hedonism, and ethical egoism.

RE/PY 2732. SUFFERING, HEALING & VALUES.
Cat. II
This course examines medicine, not from a scientific or professional view, but from a specifically humanistic approach. Using essays, films, fiction, poetry and plays, we will aim to make explicit the moral values most deeply held by practitioners in the healing professions. What other kinds of values can get in the way of those most deeply held aims? What are the responsibilities of a medical professional in today's society? What are the sources of those responsibilities? The course will focus both on professional and personal dilemmas and will help students think through some moral problems that are likely to confront them in their professional and personal lives. The class should also help prepare students to navigate through the tough moral issues they are likely to face, either as a medical professional, a citizen, a parent, a child of parents, or as potentially a sick person themselves. This class proposes to grant students the reflective time to read some of the most eloquent authors on suffering, caretaking, and sickness (for example, Oliver Sacks, Jerome Groopman, Susan Sontag, Leo Tolstoy, Virginia Woolf, Tony Kushner, Tracy Kidder, Perri Klass, etc.) and to express their reflections on these resources in effective communication.
Recommended Background: PY/RE 1731 or an introductory level literature course.
This course will be offered in 2020-21, and in alternating years thereafter.

RE 3721. TOPICS IN RELIGION.
Cat. I
This course is organized around an advanced or specialized topic in religion and provides preparation for HU 3900 Inquiry Seminars in philosophy and religion. The focus will vary, but the material will be drawn from a particular religious thinker, a particular religious tradition or a particular historical or contemporary problem. The topical theme of the class will be provided as a modified course title in the course description posted online.
Recommended background: none

SPANISH (SP)

SP 1523. ELEMENTARY SPANISH I.
Cat. I
A very intensive course that will introduce the student to the basic grammar of Spanish, emphasizing the four language skills: listening, speaking, reading and writing. It will also introduce the student to different aspects of Hispanic cultures in the U.S. and in Spanish-speaking countries. Students who have taken Spanish in high school are urged to take a placement exam before enrolling in either level of Elementary Spanish.
To enroll in this course, you must obtain written permission from one of the Spanish professors. This course is reserved for those students with only one year of high school Spanish or with no previous experience. This course is closed to native speakers of Spanish and heritage speakers except with written permission from the instructor.

SP 1524. ELEMENTARY SPANISH II.
Cat. I
A continuation of Elementary Spanish I.
Recommended background: SP 1523.
This course is closed to native speakers of Spanish and heritage speakers except with written permission from the instructor.

SP 2521. INTERMEDIATE SPANISH I.
Cat. I
A course designed to allow students to improve their written and oral skills, expand their vocabulary and review some important grammatical structures. Students will also read short stories and poems by some of the most representative Spanish American and Spanish authors, such as Horacio Quiroga, Jorge Luis Borges, Gabriela Mistral and Ana María Matute.
Recommended background: Elementary Spanish II.
This course is closed to native speakers of Spanish and heritage speakers except with written permission from the instructor.

SP 2522. INTERMEDIATE SPANISH II.
Cat. I
A continuation of Intermediate Spanish I.
Recommended background: SP 2521.
This course is closed to native speakers of Spanish and heritage speakers except with written permission from the instructor.

SP 3521. ADVANCED SPANISH I.
Cat. I
A course that continues to improve students' language skills while deepening their understanding of Hispanic cultures. Some of the topics studied are: the origins of Hispanic cultures in Spain and Spanish America; family; men and women in Hispanic societies; education; religion.
Recommended background: Intermediate Spanish II.
This course is closed to native speakers of Spanish except with written permission from the instructor.

SP 3522. ADVANCED SPANISH II.
Cat. I
A continuation of Advanced Spanish I.
Recommended background: SP 3521.
This course satisfies the Inquiry Practicum requirement.
This course is closed to native speakers of Spanish except with written permission from the instructor.

SP 3523. TOPICS IN LATIN AMERICAN CULTURE.
Cat. II
An introduction to various aspects of life in Latin American countries from early times to the present. Focusing on the social and political development of Latin America, the course will reveal the unity and diversity that characterize contemporary Latin American culture. Typical topics for study include: the precolumbian civilizations and their cultural legacy; the conquistadores and the colonial period; the independence movements; the search for and the definition of an American identity; the twentieth-century dictatorships; and the move toward democracy.
Recommended background: SP 3521 (Advanced Spanish I) and SP 3522 (Advanced Spanish II) or equivalent.
This course will be offered in 2020-21, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP 3524. SPANISH-AMERICAN LITERATURE IN THE TWENTIETH CENTURY.
Cat. II
This course, taught in the Spanish language, focuses on the major literary movements in Spanish America, from the "Modernista" movement at the turn of the century to the Latin American "Boom" of the 1960s to the political literature of the '70s and '80s. The work of representative authors, such as Rubén Dario, Julio Cortázar, Rosario Castellanos, Elena Poniatowska, will be discussed.
Recommended background: SP 3521 (Advanced Spanish I) and SP 3522 (Advanced Spanish II) or equivalent.
This course will be offered in 2019-20, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP/ID 3525. SPANISH AMERICAN FILM/MEDIA: CULTURAL ISSUES.
Cat. II
Through Latin American and Caribbean films, and other media sources, this course studies images, topics, and cultural and historical issues related to modern Latin American and the Caribbean. Within the context and influence of the New Latin American Cinema and/or within the context of the World Wide Web, radio, newspapers, and television the course teaches students to recognize cinematographic or media strategies of persuasion, and to understand the images and symbols utilized in the development of a national/regional identity. Among the topics to be studied are: immigration, gender issues, national identity, political issues, and cultural hegemonies.
Taught in advanced level Spanish. May be used toward foreign language Minor, or Major.
Recommended Background: SP 2521 and SP 2522, and SP 3523.
This course will be offered in 2019-20, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP/ID 3526. COMPARATIVE BUSINESS ENVIRONMENTS.
Cat. II
The basis of this course is a comparative study and analysis of specific Latin American and Caribbean business practices and environments, and the customs informing those practices. SP/ID 3526 focuses on countries such as Mexico, Argentina, Chile, Puerto Rico, and Costa Rica. The course's main objective is to study communication strategies, business protocol, and negotiation practices in the countries mentioned above. Through oral presentations and written essays, students will have the opportunity to explore other countries in Latin America and the Caribbean.
Taught in advanced level Spanish. May be used toward foreign language Minor, or Major.
Recommended Background: SP 2521 and SP 2522.
This course will be offered in 2020-21, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP/ID 3527. TECHNICAL AND BUSINESS SPANISH.
Cat. II
The course focuses on the linguistic concepts, terminology, and grammar involved in business and technical Spanish. Students will be required to produce and edit business documents such as letters, job applications, formal oral and written reports, etc. The objective of this course is to help students develop the basic written and oral communication skills to function in a business environment in Latin America and the Caribbean.
Recommended background: SP 2521 and SP 2522.
This course will be offered in 2019-20, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP 3528. SPANISH CULTURE AND CIVILIZATION.
Cat .II
This course is an introduction to various aspects of life in Spain, from early times to the present. The main focus is on Spain's social, political, and cultural development and its experience of diversity within its European context. Typical topics for study include: The Reconquista and the Arab influence in Spanish culture, the Spanish monarchy, its evolution into a democracy, the development of modern politics, the importance of the Spanish Civil war, and the influence of writers (such as Federico García Lorca), painters (such as Pablo Picasso), and art in general in modern Spanish culture. This course is taught in Spanish.
Recommended background: SP3521 (Advanced Spanish I) and SP 3522 (Advanced Spanish II) or equivalent.
This course will be offered in 2019-20, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP/ID 3529. CARIBBEANNESS: VOICES OF THE SPANISH CARIBBEAN.
Cat. II
A survey of Caribbean literature and arts that takes a multimedia approach to examining the different voices that resonate from the Spanish Caribbean and what appears to be a constant search for identity. By studying the works of major authors, films, music and the plastic arts, we will examine the socio-cultural context and traditions of this region in constant search for self-definition. Special attention will be given to the influential role ethnicity, colonialism, gender and socio-economic development play in the interpretation of works from Puerto Rico, Cuba, the Dominican Republic, Colombia and Venezuela as well as those of the Caribbean diaspora. This course is taught in Spanish.
Recommended background: SP3521 (Advanced Spanish I) and SP 3522 (Advanced Spanish II) or equivalent.
This course will be offered in 2019-20, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP/ID 3530. SPANISH FILM/MEDIA: CULTURAL ISSUES.
Cat. II
Through Spanish films, and other media sources, this course studies images, topics, and cultural and historical issues that have had an impact in the creation of a modern Spanish nation. This course focuses on current political and ideo-logical issues (after 1936), the importance of Spanish Civil war, gender identity, and class, cultural and power relationships. This course is taught in Spanish.
This course will be offered in 2020-21, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP/ID 3531. CONTEMPORARY US LATINO LITERATURE & CULTURE.
Cat. II
This course introduces students to the field of Latino studies, paying particular attention to the cultural productions of U.S. Latinos in film, theater, music, fiction writing and cultural criticism. At the same time that this course reflects upon a transnational framework for understanding the continuum between U.S. Latinos and Latin American/Caribbean communities, we closely examine more U.S. based arguments supporting and contesting the use of Latino as an ethnic-racial term uniting all U.S. Latino communities. We examine the ways in which U.S. Latinos have manufactured identities within dominant as well as counter cultural registers. In this course, special attention is given to the aesthetics of autobiography and to how Latino writers experiment with this genre in order to address changing constructions of immigration, language, exile, and identity. This course is taught in English.
This course will be offered in 2020-21, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

SP 3532. STUDIES IN SPANISH LITERATURE: ARTISTIC EXPRESSION AND NATION BUILDING.
Cat. II
This course introduces students to the study of Spanish literature through analytical readings of essays, poetry, drama, and fiction of representative Spanish writers from medieval to contemporary times. The selected authors to be studied reflect Spanish society's cultural and political efforts conducive to a nation building process. Among the topics to be covered are: Literary and artistic movements, nationalist and religious discourses, cultural miscegenation, gender issues, regional, political and class conflicts, the role of the intellectual, and strategies for the construction of identities.
This course is taught in Spanish.
Recommended Background: SP 3522 and SP 3528.
This course will be offered in 2020-21, and in alternating years thereafter.
This course satisfies the Inquiry Practicum requirement.

WRITING (WR) AND RHETORIC (RH)

WR 1010. ELEMENTS OF WRITING.
Cat. I
This course is designed for students who wish to work intensively on their writing. The course will emphasize the processes of composing and revising, the rhetorical strategies of written exposition and argumentation, and the reading and citation practices central to academic inquiry. In a workshop setting, students will write a sequence of short papers and complete one longer writing project based on multiple source texts; learn to read critically and respond helpfully to each other's writing; and make oral presentations from written texts. Where applicable, the topical theme of the class will be provided via the Registrar's office.

WR 1011. WRITING ABOUT SCIENCE & TECHNOLOGY.
Cat. I
This course will examine the appropriate dissemination of scientific information in common science writing genres such as science journalism, consulting reports and white papers, and policy and procedure documents. In a workshop setting, students will write and revise documents th at promote broad understanding of scientific research and analysis of specialized knowledge. Course lectures and discussions investigate ethics of scientific reporting and teach students how to recognize deceptive texts and arguments (both quantitative and qualitative). The course is reading and writing intensive and is intended for students with backgrounds in a scientific discipline who are interested in applying their disciplinary knowledge.

WR 1020. INTRODUCTION TO RHETORIC.
Cat. I
This course will apply classical and modern rhetorical concepts to analyze various texts and speeches in order to identify the means of persuasion to a particular end. Students will write short analytical papers that critically assess various rhetorical and communicative approaches. The goal of this course is to enable students to see rhetoric in action in order to both engage with the material critically as well as produce effective discourse to meet various situations.

CWR 2010. ELEMENTS OF STYLE.
Cat. I
This course will cover basic principles of prose style for expository and argumentative writing. Students will learn to evaluate writing for stylistic problems and will learn revision strategies for addressing those problems. The ultimate goal of the course is to help students write sentences and paragraphs that are clear, concise, and graceful. In the first part of the course, students will review parts of speech, basic sentence types, and sentence and paragraph structure in order to understand how sentences are put together and the impact their construction has on readers. Then, through hands-on writing exercises and extensive revision of their own and others' writing, students will learn strategies for tightening their prose (concision), achieving "flow" (cohesion and coherence) and improving usage (language specificity and precision).
Recommended background: Basic knowledge of rhetorical writing (e.g., WR 1010, Elements of Writing, WR 1011, Writing About Science & Technology, or WR 1020, Introduction to Rhetoric.

WR 2210. BUSINESS WRITING AND COMMUNICATION.
Cat. I
This course emphasizes the standard written genres of professional, workplace communication. Students will analyze the history, purposes, conventions, and social consequences of a variety of business communications, focusing on digital and print correspondence, reports, and proposals directed to internal and external audiences. Students will learn about the culture of a professional environment and the role of writing in structuring identity and relationships within that context. Classes will be conducted as interactive writing workshops in which students assess and respond to rhetorical scenarios and sample texts from a variety of professional worksites. Students will create portfolios, producing professional writing samples they may use on the job market.
Suggested background: WR 1010 or WR 1011

WR 2310. VISUAL RHETORIC.
Cat. I
This course explores how visual design is used for purposes of identification, information, and persuasion. It looks at many modes of visual communication, such as icons, logos, trademarks, signs, product packaging, infographics, posters, billboards, ads, exhibits, graffiti, page layout, films, television, videogames, and web sites. The course provides an overview of the history of graphic design movements, as well as analytical tools to understand how visual design encodes messages and the role visual communication plays in contemporary culture. Students will write about and create a number of visual media in this project-centered class.
Suggested background: WR 1010

WR/IMGD 2400. WRITING CHARACTERS FOR INTERACTIVE MEDIA & GAMES.
Cat. II
This course will present concepts and skills necessary to create compelling characters in interactive media and games. Topics covered may include the 3 dimensions of character, growth and development of the player-character and non-player characters, dialogue, character relationships and evoking emotions through rhetorical tropes.
Recommended background: Previous experience in the fundamentals of writing for interactive media and games, such as that provided by IMGD 1002: Storytelling for Interactive Media and Games.
Students may not receive credit for both IMGD/WR 2400 and IMGD 240X.

WR 3011. TEACHING WRITING
Cat. II
Teaching Writing introduces students to the theory and practice of written composition. Students research and read about the writing process and how best to support it through the practice of explicit teaching and tutoring. They learn specific strategies that can support writers as they plan, draft, and revise written work in a number of genres, and they study effective ways to provide helpful feedback on drafts. They also learn about and practice navigating the social, political and interpersonal dynamics of the teacher/tutor-student relationship through a tutoring internship at the Writing Center and through assignments prompting them to develop lesson plans and instructional handouts. This course will help students improve their own writing and read their own and others' writing more critically. It will be especially useful for those who plan to teach or tutor writing in the future.
Recommended background: WR 1010 Elements of Writing
This course will be offered in 2019-20, and in alternating years thereafter.

WR 3112. RHETORICAL THEORY.
Cat. I
Rhetoric concerns both the art of mastering the available means of persuasion and the study of how oral, written, and visual communication projects the intentions of individuals and groups, makes meanings, and affects audiences. The purpose of this course therefore is two-fold. It is intended to help students become more effective communicators by learning about the rhetorical situation and various rhetorical techniques, and it is designed to help them understand how various forms of communication work by learning some of the philosophies and strategies of rhetorical analysis.
Recommended background: Introduction to Rhetoric

WR 3210. TECHNICAL WRITING.
Cat. I
Technical writing combines technical knowledge with writing skills to communicate technology to the world. This course introduces the fundamental principles of technical communication, and the tools commonly used in the technical writing profession. Topics include user and task analysis, information design, instructional writing, and usability testing. Students learn to use the technical writing process to create user-centered documents that combine text, graphics, and visual formatting to meet specific information needs. Students create a portfolio of both hardcopy and online documentation, using professional tools such as FrameMaker, Acrobat, and RoboHelp. Recommended background: WR 1010, or equivalent writing course.

WR 3214. WRITING ABOUT DISEASE & PUBLIC HEALTH.
Cat. I
This writing workshop focuses on the purposed and genres of writing about disease and public health. We will consider how biomedical writers communicate technical information about disease and public health to general audiences; how writers capture the human experience of disease and health care; how writers treat the public policy implications of disease; and how writers design publicity to promote public health. We will examine such genres as the experimental article, news reports, medical advice, profiles, commentary, and public health messages.
Recommended background: WR 1010 Elements of Writing or equivalent writing courses.

WR 3300. CROSS-CULTURAL COMMUNICATION.
Cat II.
This course will examine how people from differing cultural backgrounds communicate, in similar and different ways among themselves, and how they endeavor to communicate across cultures. Students will develop a personal and theoretical understanding of the cultural origin of people's values, ideologies, habits, idiosyncrasies, and how they affect communication across cultural, racial, ethnic and gender lines. Through observing, studying and experiencing incidents of cross-cultural communication, they will begin to examine and develop skills that are necessary for effective understanding and for successful communication among majority and minority groups.
This course will be offered in 2020-21, and in alternate years thereafter.

WR/IMGD 3400. WRITING NARRATIVE FOR INTERACTIVE MEDIA & GAMES.
Cat. II
This writing-intensive course covers concepts and skills necessary to write and implement narrative in interactive media and games. Topics include themes and style, different types of games and platforms, systemic storytelling, linear vs. non-linear narratives, editing, writing with purpose and audience in mind, and collaboration with other members of a development team.
Recommended background: Previous experience in writing for interactive media and games, such as that provided by IMGD/WR 2400: Writing Characters for Interactive Media & Games.
Students may not receive credit for both IMGD/WR 3400 and IMGD 340X.

WR 4111. RESEARCH METHODS IN WRITING.
Cat. I
This methodology course introduces students to issues in the study of writing such as the history and uses of literacy, the relationship of thought to language, the role of writing in producing knowledge, and research on composing. The focus of the course will be on professional and academic writing. In this project-based class, students will develop research questions, construct a relevant method study, and carry out that study. The purpose of this course is to add to students analytical approaches to writing and communicative situations.
Recommended background: WR 1010 Elements of Writing, WR 2310 Rhetoric of Visual Design, WR 3112
Rhetorical Theory.

INDEPENDENT STUDY

Independent Study course designations are by subject and level of study.
In the following course numbers, [SUBJ] = SUBJECT CODE (e.g. AE, BB, ECON, ID)
[SUBJ] 1999. INDEPENDENT STUDY.
[SUBJ] 2999. INDEPENDENT STUDY.
[SUBJ] 3999. INDEPENDENT STUDY.
[SUBJ] 4999. INDEPENDENT STUDY.
Cat. I
See Independent Study policy on page 218 for information.

INTERACTIVE MEDIA & GAME DEVELOPMENT

IMGD 1000. CRITICAL STUDIES OF INTERACTIVE MEDIA AND GAMES.
Cat. I
This course introduces non-technical studies of computer-based interactive media and games. The course develops a vocabulary for discussing games and other interactive media, and tools for analyzing them. Students are expected to provide written critiques using the critical approaches presented in the course. The games and other interactive media critiqued may be commercially available or under development.

IMGD 1001. THE GAME DEVELOPMENT PROCESS.
Cat. I
This course discusses the process of game development. It examines the roles of different participants in the development process and how the technical development and the artistic development proceed in tandem. Group work is emphasized, especially the importance of collaboration between technical and artistic efforts. Students are expected to participate in game development using appropriate game development tools.
Some sections of this course may be offered as Writing Intensive (WI).

IMGD 1002. STORYTELLING IN INTERACTIVE MEDIA AND GAMES.
Cat. I
This course explores different types of story within gaming and other interactive media. It delineates between linear, branching, and emergent storytelling, identifies hybrids, and finds new modes of making compelling narrative. A variety of games are discussed, including early text-based adventures, role-playing games, shooters, and strategy games. Students will construct characters, situations, and narratives through game play and scripted cut scenes. Students will explore and use visual storytelling techniques.

IMGD 2000. SOCIAL ISSUES IN INTERACTIVE MEDIA AND GAMES.
Cat. I
This course provides students with a realistic assessment of the potential and problems related to interactive media and games, especially computer games, and their effects on society. Topics include individual and group behavior, diversity, human responsibility, ethical and legal issues, and intellectual property. The course examines the issues from various points of view, and discover the political, social, and economic agendas of the people or groups championing those points of view. Students will write papers, participate in discussions, and research related topics.
Recommended background: IMGD 1000.

IMGD 2001. PHILOSOPHY AND ETHICS OF COMPUTER GAMES.
Cat. II
This course introduces students to some of the political and ethical dimensions of the new entertainment modalities. Students will explore such issues as representation and power (e.g., gaming and disability, and race stereotyping in games), the phenomenology of virtual reality, capitalism and the commodification of leisure, gender and sexual violence, and cyberspace and democracy. Students will also develop critical tools for evaluating the ethical and social content of their own and others' games. In addition to writing several analytical papers on the critical theory of technology, students will be encouraged to work on game designs exploring philosophical or social themes.
Recommended background: IMGD 1000.
This course will be offered in 2019-20, and in alternating years thereafter.

IMGD 2030. GAME AUDIO I.
Cat. I
This course serves as an introduction to game audio, where the basics of audio theory and production are discussed along with practical applications for use in game development. Topics may include music, sound effects, dialogue, soundscape design, digital signal processing, basic audio engine principles, and the aesthetic vs. technical considerations in game audio production. Lab exercises may include an introduction to audio editing and mixing, dynamics and effects processing, creating and timing sound effects to character animations, mixing for cinematics, and audio integration using a 3D engine.
Recommended background: IMGD 1000 and IMGD 1001.
This course assumes no prior knowledge of audio production.

IMGD 2048. TECHNICAL ART AND CHARACTER RIGGING.
Cat. II
This course will focus on making digital art functional in a video game environment. Students will learn the skills necessary to create and optimize their art assets through several creative and technical solutions that are all geared towards making high quality game art.

This course will allow students to form a greater understanding of the bridge between pure art creation and interactive art implementation into a game engine. The course explores the many problems and technical restrictions one is faced with when trying to implement anything from animated characters to textures and focuses on how one can creatively apply technology to achieve high quality results.

Topics covered include: creating complex character rigs, optimizing character meshes for rigging, shader creation, optimizing UV space and baking texture files and lighting.

Recommended background: Basic knowledge of 3D modeling, texturing and animation (IMGD 2101 and IMGD 2201 or equivalent).

Students may not receive credit for both IMGD 204X and IMGD 2048.

IMGD/AR 2101. 3D MODELING I.
Cat. I
3D modeling is concerned with how to render created forms in a virtual environment. This course covers 3D modeling applications in video game development, film production, product design and fine art. Topics may include creating and armature, modeling organic and hard surfaces and sculpting using traditional techniques applied to a 3D model. Students will create works suitable for presentation in professional quality portfolio.

Recommended background: AR1100 and AR1101.

IMGD/AR 2222. 2D ANIMATION I.
Cat. I
2D Animation I teaches students how to draw, pose, breakdown and in-between characters for 2D animation, focusing on weight, balance, timing, and movement to achieve well-structured and fluid animation. Lectures and projects are conducted to train students in the twelve classical animation principles using digital 2D media. Projects and lectures are designed to practice the fundamentals of traditional frame-by-frame and hand-drawn character animation.

Recommended background: Basic knowledge of figure drawing (AR 2202) and digital art software (AR 1101) is recommended.

IMGD/AR 2333. 3D ANIMATION I.
Cat. I
3D Animation I teaches students how to use 3D animation software to apply classical animation principles into 3D work. Lectures focus on creating organic and compelling character animation through body mechanics, weight, and dynamic posing in addition to exposing students to learning how to think about character acting and staging within a 3D environment.

Recommended background: Basic knowledge digital art software (AR 1101) is recommended.

Suggested background: Basic knowledge of animation (IMGD/AR 2222).

IMGD/WR 2400. WRITING CHARACTERS FOR INTERACTIVE MEDIA & GAMES.
Cat. II
This course will present concepts and skills necessary to create compelling characters in interactive media and games. Topics covered may include the 3 dimensions of character, growth and development of the player-character and non-player characters, dialogue, character relationships and evoking emotions through rhetorical tropes.

Recommended background: Previous experience in the fundamentals of writing for interactive media and games, such as that provided by IMGD 1002: Storytelling for Interactive Media and Games.

Students may not receive credit for both IMGD/WR 2400 and IMGD 240X.

IMGD 2500. DESIGN OF TABLETOP STRATEGY GAMES.
Cat. II
The objective of the course is to teach students how to design board strategy games. The design principles are transferable to other types of games, such as computer games. Game quality issues such as rules unambiguity, depth, complexity, branching width, balance, and historical content are examined. Basic elements and types of game rules, such as map gridding, restricted play choices, resource limitations, and depths of game economics are discussed. Central to the course is the game design project: students design, playtest, and develop their own game. One two-hour laboratory a week covers play, and playtesting, and supports the game design project.

Recommended background: IMGD 1000

This course will be offered in 2020-21, and in alternating years thereafter.

IMGD/AR 2700. DIGITAL PAINTING.
Cat. I
This course covers painting techniques as applied to texturing a 3D asset or illustration/conceptual art. Topics include are color theory, study of form, lighting, applying traditional painting ideas to the digital format, character design, generation of ideas and a history of digital painting. Each class features a demonstration on the topic followed by individual critique and study. Students work towards a final project that may be suitable for an Art portfolio.

Recommended background: AR 1101, AR 2202

IMGD/AR 2740. 3D ENVIRONMENTAL MODELING.
Cat. II
The objective of this course is to teach students how to create 3D environments and props for use in digital models, simulations, games, or animation. The course will examine different types of architecture used in 3D spaces. The students will learn how to create historical and fictional interior and exterior environments; to design, model, texture, and render in high details; and to import their creation into an engine for testing. Topics may include space, human scale, set design, surface texturing, and basic camera animation. Students may not receive credit for IMGD/AR 2740 and IMGD/AR 205X.

Recommended Background: Basic 3D modeling skills (AR 1101)

This course will be offered in 2020-21, and in alternating years thereafter.

IMGD 2900. DIGITAL GAME DESIGN I.
Cat. I
Software engineering and art production are the means of digital game development, but the end is an experience. Game design is the process of creating, describing, implementing and iteratively refining that experience. This team-oriented, project-based course provides opportunities for students to develop hands-on expertise with digital game design through a combination of practical implementation, in-class critique and playtesting. A focus of the course is the functional expression of design through the use of game engine scripting.

Students keep a weekly journal of their design experiences. A final exam tests their knowledge of design concepts and terminology.

Recommended background: Intermediate programming experience (such as from CS 2102, CS 2103, or CS 1004), Knowledge of game studies (IMGD 1000 or equivalent) and the game development process (IMGD 1001or equivalent).

IMGD 2905. DATA ANALYSIS FOR GAME DEVELOPMENT.
Cat. I
This course will cover basic concepts of probability and data analysis as they apply to the design and analysis of interactive media and games. Students will study appropriate use of probability distributions in the design of interactive experiences, and the use of data analysis methods to understand user behavior in games and other interactive experiences.

Topics will include discrete and continuous probability distributions, programming techniques to produce samples from different distributions, descriptive statistics, exploratory data analysis and using existing tools to collect and analyze data from gameplay.

This course counts toward the Quantitative Science component of the university-wide Mathematics and Science Requirement for IMGD majors only.

Recommended background: High school algebra

IMGD 3000. TECHNICAL GAME DEVELOPMENT I.
Cat. I
This course teaches technical Computer Science aspects of game development, with the focus of the course on low-level programming of a computer games. Topics include 2D and 3D game engines, simulation-type games, analog and digital controllers and other forms of tertiary input. Students will implement games or parts of games, including exploration of graphics, sound, and music as it affects game implementation.

Recommended background: CS 2303.

IMGD 3030. GAME AUDIO II.
Cat. II
Game Audio II serves as an intermediate level audio design course, where digital recording principles and techniques are studied along with their practical applications for use in game development. Students will also gain deeper insight into 2-D vs. 3-D audio propagation, as well as learn more complex techniques in digital editing, mixing, signal processing, mastering, and playback strategies. Lab exercises may include interactive dialogue scripting and recording; loop-based music production; custom sound effects creation and Foley design; and audio engine integration. A team project will be the creation of a comprehensive game sound effects library over the course of the term.

Recommended background: Game Audio (IMGD 2030)

This course will be offered in 2020-21, and in alternating years thereafter.

IMGD 3100. NOVEL INTERFACES FOR INTERACTIVE ENVIRONMENTS.
Cat. II
This course focuses on the design and evaluation of novel user interfaces that provide greater input and output expressiveness than the keyboard, mouse, or game pad. The course covers the related applications of immersive gaming, teleoperated robotics, and mobile users. Input sensors, such as those providing motion, attitude, and pressure data, are used to explore novel input methods, and how they may be effectively used to design innovative experiences. Through a combination of lecture and hands-on work, students learn to build prototype systems and to critically evaluate different alternatives. Students are expected to program several alternative input/output systems as part of this course

Recommended background: IMGD 1001, and either CS 2301 or CS 2303

This course will be offered in 2020-21, and in alternating years thereafter.

IMGD/AR 3101. 3D MODELING II.
Cat. I
This course will build upon the skills learned in 3D MODELING with studies in life drawing/anatomy study and application towards completed character models. Students will create high resolution sculpts for real time game environments and animation. Topics covered will be character design as it applies to 3D MODELING, creating realistic design sculpts and incorporating them into a game environment as well as the study of anatomy as it applies to organic modeling.

Recommended background: AR 1101, IMGD/AR 2101, AR 2202

IMGD/AR 3200. INTERACTIVE ELECTRONIC ARTS.
Cat. I
This course introduces students to techniques and processes for the creation of real-time, interactive works of art. Students learn to use electronic sensors and other tools for audio, graphics, and video processing, as well as design customized software interfaces to create interactive artworks that respond to users and their environment. The course also introduces students to the work of significant contemporary arts practitioners as well as their historical precedents, with a special emphasis on inter-media works that bridge visual art, music composition, and the performing arts. Topics may include electronic musical instruments and performance interfaces, computer vision, VJing, electronically-augmented dance, controller hacking, wired clothing, networked collaboration and mobile media, and algorithmic and generative art.

Recommended background: Animation (AR/IMGD 2101 or equivalent), and exposure to digital audio or music and introductory programming.

IMGD/AR 3222. 2D ANIMATION II.
Cat. I
This course will build upon the techniques learned in IMGD/AR 2222. Students will learn to apply the animation principles to character animation. Students are taught how to tell a compelling, character-driven story through a focus on character acting techniques such as body language, lip syncing, facial animation, and micro expressions. Additional topics covered may include sprites for games, biped and quadruped animation, and 2D animation pipelines. Students will create animated sequences that are intended to serve a narrative structure for games and other media.

Recommended background: Knowledge of digital 2D animation techniques and classical animation principles (IMGD/AR 2222).

IMGD/AR 3333. 3D ANIMATION II.
Cat. I
This course will build upon the techniques learned in IMGD/AR 2333. Students will learn to apply the animation principles with a focus on character acting and cinematic animation. Students are taught how to tell a compelling, character-driven story through a focus on acting techniques such as body language, lip syncing, facial animation, and micro expressions whilst incorporating digital cinematography techniques. Additional topics covered may include creating 3D simulations for hair and cloth, biped and quadruped animation, and 3D animation pipelines. Students will create animated sequences that are intended to serve a narrative structure for games and other media.

Recommended background: Knowledge of digital 3D animation techniques and classical animation principles (IMGD/AR 2333).

IMGD/WR 3400. WRITING NARRATIVE FOR INTERACTIVE MEDIA & GAMES.
Cat. II
This writing-intensive course covers concepts and skills necessary to write and implement narrative in interactive media and games. Topics include themes and style, different types of games and platforms, systemic storytelling, linear vs. non-linear narratives, editing, writing with purpose and audience in mind, and collaboration with other members of a development team.

Recommended background: Previous experience in writing for interactive media and games, such as that provided by IMGD/WR 2400: Writing Characters for Interactive Media & Games.

Students may not receive credit for both IMGD/WR 3400 and IMGD 340X.

IMGD 3500. ARTISTIC GAME DEVELOPMENT I.
Cat. I
This course focuses on the unique problems presented to the artist when working in game development. Students will learn game art pipelines and how to prepare art assets for use in game engines. Topics may include modular level design, 3D architecture, texturing and shaders, high poly and low poly workflows, environments, lighting, particle effects, and character animation for games. Students will create original art for compelling game experiences by designing their own levels.

Recommended background: 3D modeling (IMGD/AR 2101 and 3101), digital painting (IMGD/AR 2700), 3D animation (IMGD/AR 2333).

IMGD/AR 3700. CONCEPT ART AND CREATIVE ILLUSTRATION.
Cat. I
This course covers drawing as it applies to concept art and illustration. The course begins with study of a human model and representational drawing. Following this, students work on drawing from the mind and applying the lessons learned from the figure drawing to creating concept art and illustration. Topics covered are shape recognition and recalling, inventing from the mind, creative starters, study of form and light, visual composition and developing a personal approach, working with individual strengths to create a compelling visual design. Students create a series of concept art exercises and apply these skills towards a personal project of their own.

Recommended background: AR 2202, IMGD/AR 2700

IMGD 3900. DIGITAL GAME DESIGN II.
Cat. II
This team-oriented, project-based course will provide opportunities for students to deepen their experience and understanding of digital game design concepts through a combination of thorough design, practical implementation, playtesting and in-class game critique.

Students will prepare and present design treatments, develop hands-on expertise with game scripting, and study methods of collecting and analyzing gameplay data. A final project and presentation will test their creativity and demonstrate their practical mastery of game design concepts.

Recommended background: IMGD 2900: Digital Game Design I, and basic knowledge of statistical data analysis such as that provided by IMGD 2905: Data Analysis for Game Development.

IMGD 4000. TECHNICAL GAME DEVELOPMENT II.
Cat. I
This course focuses on the application of advanced Computer Science topics as they impact game development. Networking and distributed systems issues are addressed, including scalability and latency compensation techniques, for designing games for a online multi-player environments. AI, graphics and physics techniques specific to game development are discussed. Students will implement games or parts of games that apply advanced Computer Science topics.

Recommended background: IMGD 3000.

IMGD 4099. SPECIAL TOPICS IN IMGD.
Cat. II (1/6 – 1/3 unit)
Arranged by individual faculty with special expertise, this course explores emerging and experimental topics that are not covered by the regular IMGD offerings. Content and format varies to suit the interests and needs of the faculty and students. Specific course descriptions are disseminated by IMGD program in advance of the offering. This course may be repeated for different topic offerings.

Recommended background: Varies depending on topic.

IMGD/CS 4100. ARTIFICIAL INTELLIGENCE FOR INTERACTIVE MEDIA AND GAMES.
Cat. II
Advanced software design and programming techniques from artificial intelligence are key contributors to the experience of modern computer games and virtual environments, either by directly controlling a non-player character or through more subtle manipulation of the environment. This course will cover the current state of the art in this area, as well as prepare students for the next generation of AI contributions. We will study the application of AI techniques such as search, planning, machine learning, emotion modeling and natural language processing, to game problems such as navigation, strategy, believability and narrative control. Students will implement several small AI demonstration games.

Recommended background: IMGD 4000.

Students may not receive credit for both IMGD 4100 and IMGD 400X.

This course will be offered in 2019-20, and in alternating years thereafter.

IMGD 4200. HISTORY AND FUTURE OF IMMERSIVE AND INTERACTIVE MEDIA.
Cat. II
This course will familiarize students with the history of the development, deployment, commercialization, and evolution of immersive and active media. The lesson plan will cover a broad range of enabling technologies, such as geometric perspective drawing, pre-20th-century panoramic displays, photography and the stereoscope, sound recording and reproduction, motion pictures, radio and television, the planetarium, immersive and 3-dimensional cinema, and special attraction venues, with a particular focus on digital games. Current trends and future directions will also be considered. Students will attend seminars and lectures, read and discuss texts on media history and aesthetics, and write an original research paper. Midterm and final exams test students' knowledge and understanding of important events and developments. A student may not receive credit for both IMGD 4200 and IMGD 5200.

Recommended background: IMGD 1000, and either IMGD 2000 or IMGD 2001.

This course will be offered in 2019-20, and in alternating years thereafter.

IMGD 4403. MOTION CAPTURE TECHNIQUES.
Cat. II
This course will introduce students to the principles of motion capture as applied to the production of digital games and cinema. Topics will include the study of different forms of mocap technology, the design of efficient animation pipelines, techniques for combining keyed and mocap animation, and real-time capture into game engines. Students will gain experience in directing actors, blending hand-keyed animations, applying the laws of physics to motion data sets, building tools and troubleshooting captured data.
Students cannot receive credit for both IMGD 4403 and IMGD 440X.

Recommended background: Students should have knowledge of basic 3D animation principles and software such as is provided by IMGD/AR 2333: 3D Animation I. They should also have knowledge of structural anatomy and kinematics such as is provided by IMGD 2048: Technical Art and Character Rigging.

This course will be offered in 2021-22, and in alternating years thereafter.

IMGD 4500. ARTISTIC GAME DEVELOPMENT II.
Cat. I
This course focuses on the integration and organization of the various artistic elements used in game development. The course examines user interaction, interface design, and existing paradigms in current games. Students will combine elements of level design, animation, music, sound, and writing to create an aesthetically appealing game.

Recommended background: IMGD 1002, IMGD 3500, MU 1611.

IMGD 4600. SERIOUS GAMES.
Cat. II
This course explores the application of the technologies and design principles of interactive media and game development beyond traditional entertainment. The purpose of such applications is typically to change people's behaviors, knowledge and/or attitudes in diverse areas including health care, training, education, simulation, politics, marketing and art. Students read about, experiment with, compare and discuss examples, as well as the underlying philosophies and issues specific to this genre, such as domain analysis and rigorous evaluation. Students in groups also research a new application and produce a detailed design document and mock-up. Advanced programming skill is not required, but a background in game design is strongly recommended.

Recommended background: IMGD 1001 and either IMGD 2000 or IMGD 2001.

Students may not receive credit for both IMGD 4600 and IMGD 404X.

This course will be offered in 2019-20, and in alternating years thereafter.

IMGD 4700. ADVANCED STORYTELLING: QUEST LOGIC AND LEVEL DESIGN.
Cat. II
This course provides an in-depth examination of storytelling as it is currently done in 2D and 3D games through a study of quests and construction of gaming spaces. Level designers turn stories into games through building virtual spaces and populating them with non-player characters who have their own objectives. Cinematics are used to extend the narrative space. The course requires students to build multiple virtual spaces that have a history and a population with present needs. Students need to work out plotting through the logic of a quest, build several areas that supports that logic and create cinematics to extend their narrative space.

Recommended background: IMGD 1002, or equivalent knowledge.

Students may not receive credit for both IMGD 4700 and IMGD 403X.

This course will be offered in 2020-21, and in alternating years thereafter.

IMGD 4900. DIGITAL GAME DESIGN STUDIO.
Cat. II
This studio course will provide students an opportunity to collaborate on the creation of an original game project, with an emphasis on the importance of scoping and a thorough, well-documented design. Students will form project teams, create a team Web site, and design, implement and test their project using industry-standard tools and methods.

Recommended background: IMGD 3900 (Digital Game Design II)

This course will be offered in 2019-20, and in alternating years thereafter.

INTERDISCIPLINARY

FY 1100 & FY 1101. THE GREAT PROBLEMS SEMINARS.
Cat. I
The Great Problems Seminars (GPS) are a two course sequence designed to engage Worcester Polytechnic Institute's first-year students with current events, societal problems, and human needs. Each seminar starts with an important problem and introduces some of the key disciplinary tools that could be used to attack the problem. The focus for most of the second course will be a research project related to the GPS theme. Students will present their project work in a poster session at the end of the second term. Each seminar is developed and presented by an interdisciplinary pair of faculty. To participate, students must enroll in the two course sequence. Academic credit for the GPS will depend on the theme and the faculty who develop the seminar.

FY 1800. DISCOVERING MAJORS AND CAREERS.
(1/12 unit)
This course is open to all students who are undecided about or are thinking about changing their academic major. Students will conduct a self-assessment utilizing career assessment tools, research majors of interest and career paths, attend major panels, speak to students/faculty in majors of interest, and participate in informational interviews with alumni. Students will meet individually with Peer Advisors and/or a CDC staff member at least three times throughout the course.

ID 2000. MAPPING YOUR MISSION.
Cat. I (1/6 unit)
Every student that graduates from WPI has a major, but what about a mission? This course helps participants explore their personal values, strengths, and talents and the ways they can use these personal characteristics to improve the world around them. Through the course, participants will identify a personal mission and a plan to work toward achieving their mission. Participants will explore the ways their major and their mission can intersect.

Students may not receive credit for ID 200X and ID 2000.

ID/SS 2050. SOCIAL SCIENCE RESEARCH FOR THE IQP.
Cat. I
This course is open to students accepted to off-campus IQP centers and programs. The course introduces students to research design, methods for social science research, and analysis. It also provides practice in specific research and field skills using the project topics students have selected in conjunction with sponsoring agencies. Students learn to develop social science hypotheses based upon literature reviews in their topic areas and apply concepts drawn from social psychology, anthropology, sociology, economics and other areas as appropriate. Students make presentations, write an organized project proposal, and develop a communication model for reporting their project findings.

Some sections of this course may be offered as Writing Intensive (WI).

ID 2100. DISEASE DETECTIVES: AN INTRODUCTION TO EPIDEMIOLOGY.
Cat. II
In this course, we will learn about the principles of epidemiology and the role epidemiologist play in responding to disease outbreaks and promoting public health through exploration of a series of real life cases studies. We will analyze the burden of communicable diseases today and emerging disease. We will discuss the role of current health practices and priorities as well as global organization and institutional players. Students will be introduced to the basic principles and methods used in epidemiology to study the distribution and determinants of disease in human populations and in the development of prevention and intervention strategies. The course will take an interdisciplinary approach as epidemiologist relay on many different disciplines such as biology for understanding disease processes, statistics for making efficient and appropriate use of data, social science for understanding behavior, and engineering for analysis and assessment tools. Class sessions will consist of lecture, intensive small group discussion, and case analyses.

This course will be offered in 2020-21, and in alternating years thereafter.

ID 3100. TEACHING METHODS IN MATHEMATICS AND SCIENCE.
Cat. I
Within the context of contemporary secondary education in mathematics and science (biology, chemistry, physics), ID 3100 introduces and demonstrates effective teaching methods as they relate to curriculum goals and current methods of assessment. These methods take into account diverse learning styles as well as various technological resources. Topics to be covered include: a brief history of education; curriculum and course guidelines (Massachusetts Education Reform and regulations 603 CMR 7.00, state curricular frameworks, national standards); legal issues; developing a course syllabus; and the issue of breadth versus depth in course planning and delivery. The course also covers practical questions of organizing, delivering and assessing a course. This course is intended primarily for students interested in completing the Massachusetts requirements for teacher licensing. This program is aimed primarily at majors in mathematics, physics, chemistry, biology, and certain engineering fields wishing to be licensed to teach in middle or high school in one of those disciplines. A portion of the course requires students to complete field work in a local classroom to assist them in beginning to acquire the appropriate skills to conduct their own classes in mathematics, science, or engineering at the secondary school level.

Recommended background: Principals of educational psychology including: understanding student characteristics, the learning process, motivation to learn, student diversity; evaluating student learning (PSY 2401)

Note, this course is typically held off campus at Doherty High School (approximately 1 mile from campus) so please plan for travel time when signing up.

ID/AR 3150. LIGHT, VISION AND UNDERSTANDING.
Cat. II
By using material from the sciences and the humanities this course examines the ways in which ideas of knowledge and of human nature have been fashioned. The specific topics include physical theories about light, biological and psychological theories of visual perception, and artistic theories and practices concerned with representation. The mixing of material from different academic disciplines is deliberate, and meant to counter the notion that human pursuits are "naturally" arranged in the neat packages found in the modern university. The course draws upon the physical and social sciences, and the humanities, to examine how those fields relate to one another, and how they produce knowledge and self-knowledge. Cultural as well as disciplinary factors are assessed in this process.

Light, Vision and Understanding is conducted as a seminar. The diverse collection of reading materials includes a number of primary texts in different fields. In addition, the students keep a journal in which they record the results of numerous individual observations and experiments concerning light and visual perception. The course can fit into several areas of depth as well as serve as a starting point for an IQP. There are no specific requirements for this course, although some knowledge of college-level physics, as well an acquaintance with the visual arts, is helpful.

This course will be offered in 2020-21, and in alternating years thereafter.

ID 3200. SHELTERED ENGLISH IMMERSION ENDORSEMENT COURSE FOR TEACHERS.
Cat. I
This course is to prepare undergraduates looking to become future Commonwealth teachers with the knowledge and skills to effectively shelter their content instruction, so that the growing population of English language learners (ELLs) can access curriculum, achieve academic success, and contribute their multilingual and multicultural resources as participants and future leaders in the 21st century global economy.

Recommended background: Teaching Methods or equivalent.

ID/SP 3525. SPANISH AMERICAN FILM/MEDIA: CULTURAL ISSUES.
Cat. II
Through Latin American and Caribbean films, and other media sources, this course studies images, topics, and cultural and historical issues related to modern Latin American and the Caribbean. Within the context and influence of the New Latin American Cinema and/or within the context of the World Wide Web, radio, newspapers, and television the course teaches students to recognize cinematographic or media strategies of persuasion, and to understand the images and symbols utilized in the development of a national/regional identity. Among the topics to be studied are: immigration, gender issues, national identity, political issues, and cultural hegemonies.

Taught in advanced level Spanish. May be used toward foreign language Minor, or Major.

Recommended Background: SP 2521 and SP 2522, and SP 3523.

This course will be offered in 2019-20, and in alternating years thereafter.

ID/SP 3526. COMPARATIVE BUSINESS ENVIRONMENTS.
Cat. II
The basis of this course is a comparative study and analysis of specific Latin American and Caribbean business practices and environments, and the customs informing those practices. ID/SP 3526 focuses on countries such as Mexico, Argentina, Chile, Puerto Rico, and Costa Rica. The course's main objective is to study communication strategies, business protocol, and negotiation practices in the countries mentioned above. Through oral presentations and written essays, students will have the opportunity to explore other countries in Latin America and the Caribbean.

Taught in advanced level Spanish. May be used toward foreign language Minor, or Major.

Recommended Background: SP 2521 and SP 2522.

This course will be offered in 2020-21, and in alternating years thereafter.

ID/SP 3527. TECHNICAL AND BUSINESS SPANISH.
Cat. II
The course focuses on the linguistic concepts, terminology, and grammar involved in business and technical Spanish. Students will be required to produce and edit business documents such as letters, job applications, formal oral and written reports, etc. The objective of this course is to help students develop the basic written and oral communication skills to function in a business environment in Latin America and the Caribbean.

Recommended background: SP 2521 and SP 2522.

This course will be offered in 2019-20, and in alternating years thereafter.

ID/SP 3529. CARIBBEANNESS: VOICES OF THE SPANISH CARIBBEAN.
Cat. II
A survey of Caribbean literature and arts that takes a multimedia approach to examining the different voices that resonate from the Spanish Caribbean and what appears to be a constant search for identity. By studying the works of major authors, films, music and the plastic arts, we will examine the socio-cultural context and traditions of this region in constant search for self-definition. Special attention will be given to the influential role ethnicity, colonialism, gender and socio-economic development play in the interpretation of works from Puerto Rico, Cuba, the Dominican Republic, Colombia and Venezuela as well as those of the Caribbean diaspora. This course is taught in Spanish.

Recommended background: SP3521 (Advanced Spanish I) and SP 3522 (Advanced Spanish II) or equivalent.

This course will be offered in 2019-20, and in alternating years thereafter.

ID/SP 3530. SPANISH FILM/MEDIA: CULTURAL ISSUES.
Cat. II
Through Spanish films, and other media sources, this course studies images, topics, and cultural and historical issues that have had an impact in the creation of a modern Spanish nation. This course focuses on current political and ideological issues (after 1936), the importance of Spanish Civil war, gender identity, and class, cultural and power relationships. This course is taught in Spanish.

This course will be offered in 2020-21, and in alternating years thereafter.

ID/SP 3531. CONTEMPORARY US LATINO LITERATURE & CULTURE.
Cat. II
This course introduces students to the field of Latino studies, paying particular attention to the cultural productions of U.S. Latinos in film, theater, music, fiction writing and cultural criticism. At the same time that this course reflects upon a transnational framework for understanding the continuum between U.S. Latinos and Latin American/Caribbean communities, we closely examine more U.S. based arguments supporting and contesting the use of Latino as an ethnic-racial term uniting all U.S. Latino communities. We examine the ways in which U.S. Latinos have manufactured identities within dominant as well as counter cultural registers. In this course, special attention is given to the aesthetics of autobiography and to how Latino writers experiment with this genre in order to address changing constructions of immigration, language, exile, and identity. This course is taught in English.

This course will be offered in 2020-21, and in alternating years thereafter.

MATHEMATICAL SCIENCES

The second digit in mathematical sciences course numbers is coded as follows:

0 — Basic
2 — Applied mathematics (general)
4 — Applied mathematics (differential equations)
6 — Statistics and probability
8 — Mathematics (general)

MA 1020. CALCULUS I WITH PRELIMINARY TOPICS.
Cat. I (14-week course)
This course includes the topics of MA 1021 and also presents selected topics from algebra, trigonometry, and analytic geometry.

This course, which extends for 14 weeks and offers 1/3 unit of credit, is designed for students whose precalculus mathematics is not adequate for MA 1021.

Although the course will make use of computers, no programming experience is assumed.

Students may not receive credit for both MA 1020 and MA 1021.

MA 1021. CALCULUS I.
Cat. I
This course provides an introduction to differentiation and its applications.

Topics covered include: functions and their graphs, limits, continuity, differentiation, linear approximation, chain rule, min/max problems, and applications of derivatives.

Recommended background: Algebra, trigonometry and analytic geometry.

Although the course will make use of computers, no programming experience is assumed.

Students may not receive credit for both MA 1021 and MA 1020.

MA 1022. CALCULUS II.
Cat. I
This course provides an introduction to integration and its applications.

Topics covered include: inverse trigonometric functions, Riemann sums, fundamental theorem of calculus, basic techniques of integration, volumes of revolution, arc length, exponential and logarithmic functions, and applications.

Recommended background: MA 1021. Although the course will make use of computers, no programming experience is assumed.

MA 1023. CALCULUS III.
Cat. I
This course provides an introduction to series, parametric curves and vector algebra.

Topics covered include: numerical methods, indeterminate forms, improper integrals, sequences, Taylor's theorem with remainder, convergence of series and power series, polar coordinates, parametric curves and vector algebra.

Recommended background: MA 1022. Although the course will make use of computers, no programming experience is assumed.

MA 1024. CALCULUS IV.
Cat. I
This course provides an introduction to multivariable calculus.

Topics covered include: vector functions, partial derivatives and gradient, multivariable optimization, double and triple integrals, polar coordinates, other coordinate systems and applications.

Recommended background: MA 1023. Although the course will make use of computers, no programming experience is assumed.

MA 1033. THEORETICAL CALCULUS III.
Cat. I
This course will cover the same material as MA 1023 Calculus III but from a different perspective. A more rigorous study of sequences and series will be undertaken: starting from the least upper bound property in R, the fundamental theorems for convergent series will be proved. Convergence criteria for series will be rigorously justified and L'Hospital's rule will be introduced and proved. Homework problems will include a blend of computational exercises as usually assigned in MA 1023 Calculus III and problems with a stronger theoretical flavor.

Recommended background: Differential and integral calculus (MA 1021 and MA 1022, or equivalent).

Note: Students can receive credit for this class and MA 1023 Calculus III.

MA 1034. THEORETICAL CALCULUS IV.
Cat. I
This course will cover the same material as MA 1024 Calculus IV from a more mathematically rigorous perspective. The course gives a rigorous introduction of differentiation and integration for functions of one variable. After introducing vector functions, differentiation and integration will be extended to functions of several variables.

Recommended background: Theoretical Calculus III (MA 1033, or equivalent).

Note: Students can receive credit for this class and MA 1024 Calculus IV.

MA 1120. CALCULUS II. (SEMESTER VERSION)
Cat. I (14-week course)
The topics for integral calculus (MA 1022) are covered in this course: the concept of the definite integral, the Fundamental Theorem of Calculus, integration techniques, and applications of integration. Applications include: area, volume, arc length, center of mass, work, force, and exponential growth and decay. Logarithmic and exponential functions are studied in depth. Arithmetic and geometric sequences and series will also be covered. Key historical events in the development of integral calculus are examined. Technology will be used as appropriate to support the material being studied.

This course extends for 14 weeks and offers 1/3 unit of credit. It is designed for students who would benefit from additional contact hours and who need to strengthen their mathematical background. Although the course will make use of computers, no programming experience is assumed.

Students may not receive credit for both MA 1120 and MA 1022 or MA 1102.

MA 1801. DENKSPORT.
Cat. I (1/12 Unit)
Problem solving is a fundamental mathematical skill. In this course students will be exposed to problems coming from a wide range of mathematical disciplines; and will work together in a collaborative environment to explore potential solutions. Discussion problems may be inspired by the research of faculty leading the discussion, by past mathematical competitions (such as the Putnam Competition) or elsewhere. This course meets once per week, with an emphasis on discussion and exploration of problems. There will be no exam and no assigned homework. Grading is by participation only. This course may be taken multiple times; content will vary depending on the speakers. Grading for this course will be on a Pass/NR basis.

Recommended background: Curiosity about Mathematics

MA 1971. BRIDGE TO HIGHER MATHEMATICS.
Cat. I
The principal aim of this course is to practice mathematical problem interpretation, proof techniques, and question formulation. The course is intended not only for beginning students in the mathematical sciences, but also for all students interested in mathematical art and rigor. Students in the course will be expected to explain, justify, defend, disprove, conjecture and verify mathematical statements, both orally and in writing, in order to develop proof-writing skills.

(These skills should prove useful in more advanced mathematics courses). Topics covered include basic logic; basic set theory; definitions and properties of functions; definitions and properties of binary relations; fundamental proof techniques, including proof by induction. Depending on student background and instructor preferences, the course objectives may be conveyed through a selection of problems from various mathematical sub-disciplines, through discussions of current events in the mathematical sciences, including recently solved problems and open challenges facing today's scientists, or through discussions of applications of mathematics.

Recommended background: at least two courses in Mathematical Sciences at WPI, or equivalent.

MA 2051. ORDINARY DIFFERENTIAL EQUATIONS.
Cat. I
This course develops techniques for solving ordinary differential equations. Topics covered include: introduction to modeling using first-order differential equations, solution methods for linear higher-order equations, qualitative behavior of nonlinear first-order equations, oscillatory phenomena including spring-mass system and RLC-circuits and Laplace transform. Additional topics may be chosen from power series method, methods for solving systems of equations and numerical methods for solving ordinary differential equations.

Recommended background: MA 1024.

MA 2071. MATRICES AND LINEAR ALGEBRA I.
Cat. I
This course provides an introduction to the theory and techniques of matrix algebra and linear algebra. Topics covered include: operations on matrices, systems of linear equations, linear transformations, determinants, eigenvalues and eigenvectors, least squares, vector spaces, inner products, introduction to numerical techniques, and applications of linear algebra. Credit may not be earned for this course and MA 2072.

Recommended background: None, although basic knowledge of equations for planes and lines in space would be helpful.

MA 2072. ACCELERATED MATRICES AND LINEAR ALGEBRA I.
Cat. I
This course provides an accelerated introduction to the theory and techniques of matrix algebra and linear algebra, aimed at Mathematical Sciences majors and others interested in advanced concepts of linear algebra. Topics covered include: matrix algebra, systems of linear equations, linear transformations, determinants, eigenvalues and eigenvectors, the method of least squares, vector spaces, inner products, non-square matrices and singular value decompositions. Students will be exposed to computational and numerical techniques, and to applications of linear algebra, particularly to Data Science. Credit may not be earned for this course and MA 2071.

Recommended background: Basic knowledge of matrix algebra

MA 2073. MATRICES AND LINEAR ALGEBRA II.
Cat. I
This course provides a deeper understanding of topics introduced in MA 2071, and continues the development of linear algebra. Topics covered include: abstract vector spaces, linear transformations, matrix representations of a linear transformation, determinants, characteristic and minimal polynomials, diagonalization, eigenvalues and eigenvectors, the matrix exponential, inner product spaces. This course is designed primarily for Mathematical Science majors and those interested in the deeper mathematical issues underlying linear algebra.

Recommended background: MA 2071 or MA 2072.

MA 2201/CS 2022. DISCRETE MATHEMATICS.
Cat. I
This course serves as an introduction to some of the more important concepts, techniques, and structures of discrete mathematics providing a bridge between computer science and mathematics. Topics include sets, functions and relations, propositional and predicate calculus, mathematical induction, properties of integers, counting techniques and graph theory. Students will be expected to develop simple proofs for problems drawn primarily from computer science and applied mathematics.

Recommended background: None.

MA 2210. MATHEMATICAL METHODS IN DECISION MAKING.
Cat. I
This course introduces students to the principles of decision theory as applied to the planning, design and management of complex projects. It will be useful to students in all areas of engineering, actuarial mathematics as well as those in such interdisciplinary areas as environmental studies. It emphasizes quantitative, analytic approaches to decision making using the tools of applied mathematics, operations research, probability and computations. Topics covered include: the systems approach, mathematical modeling, optimization and decision analyses. Case studies from various areas of engineering or actuarial mathematics are used to illustrate applications of the materials covered in this course.

Recommended background: MA 1024. Suggested background: Familiarity with vectors and matrices. Although the course makes use of computers, no programming experience is assumed. Students who have received credit for CE 2010 may not receive credit for MA 2210.

MA 2211. THEORY OF INTEREST I.
Cat. I
An introduction to actuarial mathematics is provided for those who may be interested in the actuarial profession. Topics usually included are: measurement of interest, including accumulated and present value factors; annuities certain; amortization schedules and sinking funds; and bonds.

Recommended background: Single variable calculus (MA 1021 and MA 1022 or equivalent) and the ability to work with appropriate computer software.

Students may not receive credit for both MA 2211 and MA 3211

MA 2212. THEORY OF INTEREST II.
Cat. I
This course covers topics in fixed income securities. Topics are chosen to cover the mechanics and pricing of modern-day fixed income products and can include: yield curve theories; forward rates; interest rate swaps; credit-default swaps; bonds with credit risk and options; bond duration and convexity; bond portfolio construction; asset-backed securities, including collateralized debt obligations and mortgage-backed securities with prepayment risk; asset-liability hedging; applications of binomial interest rate trees.

Recommended background: An introduction to theory of interest (MA 2211 or equivalent) and the ability to work with appropriate computer software.

MA 2251. VECTOR AND TENSOR CALCULUS.
Cat. I
This course provides an introduction to tensor and vector calculus, an essential tool for applied mathematicians, scientists, and engineers.

Topics covered include: scalar and vector functions and fields, tensors, basic differential operations for vectors and tensors, line and surface integrals, change of variable theorem in integration, integral theorems of vector and tensor calculus. The theory will be illustrated by applications to areas such as electrostatics, theory of heat, electromagnetics, elasticity and fluid mechanics.

Recommended background: MA 1024.

MA 2271. GRAPH THEORY.
Cat. II
This course introduces the concepts and techniques of graph theory—a part of mathematics finding increasing application to diverse areas such as management, computer science and electrical engineering. Topics covered include: graphs and digraphs, paths and circuits, graph and digraph algorithms, trees, cliques, planarity, duality and colorability.

This course is designed primarily for Mathematical Science majors and those interested in the deeper mathematical issues underlying graph theory.

Undergraduate credit may not be earned both for this course and for MA 3271.

Recommended background: MA 2071.

This course will be offered in 2020-21, and in alternating years thereafter.

MA 2273. COMBINATORICS.
Cat. II
This course introduces the concepts and techniques of combinatorics— a part of mathematics with applications in computer science and in the social, biological, and physical sciences. Emphasis will be given to problem solving. Topics will be selected from: basic counting methods, inclusion-exclusion principle, generating functions, recurrence relations, systems of distinct representatives, combinatorial designs, combinatorial algorithms and applications of combinatorics.

This course is designed primarily for Mathematical Sciences majors and those interested in the deeper mathematical issues underlying combinatorics.

Undergraduate credit may not be earned both for this course and for MA 3273.

Recommended background: MA 2071.

This course will be offered in 2019-20, and in alternating years thereafter.

MA 2431. MATHEMATICAL MODELING WITH ORDINARY DIFFERENTIAL EQUATIONS.
Cat. I
This course focuses on the principles of building mathematical models from a physical, chemical or biological system and interpreting the results. Students will learn how to construct a mathematical model and will be able to interpret solutions of this model in terms of the context of the application. Mathematical topics focus on solving systems of ordinary differential equations, and may include the use of stability theory and phase-plane analysis. Applications will be chosen from electrical and mechanical oscillations, control theory, ecological or epidemiological models and reaction kinetics. This course is designed primarily for students interested in the deeper mathematical issues underlying mathematical modeling. Students may be required to use programming languages such as Matlab or Maple to further investigate different models.

Recommended background: multivariable calculus (MA 1024 or equivalent), ordinary differential equations (MA 2051 or equivalent), and linear algebra (MA 2071 or equivalent).

MA 2610. APPLIED STATISTICS FOR THE LIFE SCIENCES.
Cat. I
This course is designed to introduce the student to statistical methods and concepts commonly used in the life sciences. Emphasis will be on the practical aspects of statistical design and analysis with examples drawn exclusively from the life sciences, and students will collect and analyze data. Topics covered include analytic and graphical and numerical summary measures, probability models for sampling distributions, the central limit theorem, and one and two sample point and interval estimation, parametric and non-parametric hypothesis testing, principles of experimental design, comparisons of paired samples and categorical data analysis. Undergraduate credit may not be earned for both this course and for MA 2611.

Recommended background: MA 1022.

MA 2611. APPLIED STATISTICS I.
Cat. I
This course is designed to introduce the student to data analytic and applied statistical methods commonly used in industrial and scientific applications as well as in course and project work at WPI. Emphasis will be on the practical aspects of statistics with students analyzing real data sets on an interactive computer package.

Topics covered include analytic and graphical representation of data, exploratory data analysis, basic issues in the design and conduct of experimental and observational studies, the central limit theorem, one and two sample point and interval estimation and tests of hypotheses.

Recommended background: MA 1022.

MA 2612. APPLIED STATISTICS II.
Cat. I
This course is a continuation of MA 2611.

Topics covered include simple and multiple regression, one and two-way tables for categorical data, design and analysis of one factor experiments and distribution-free methods.

Recommended background: MA 2611.

MA 2621. PROBABILITY FOR APPLICATIONS.
Cat. I
This course is designed to introduce the student to probability.

Topics to be covered are: basic probability theory including Bayes theorem; discrete and continuous random variables; special distributions including the Bernoulli, Binomial, Geometric, Poisson, Uniform, Normal, Exponential, Chi-square, Gamma, Weibull, and Beta distributions; multivariate distributions; conditional and marginal distributions; independence; expectation; transformations of univariate random variables.

Recommended background: MA 1024.

MA 2631. PROBABILITY THEORY.
Cat. I
The purpose of this course is twofold:

- To introduce fundamental ideas and methods of mathematics using the study of probability as the vehicle. These ideas and methods may include systematic theorem-proof development starting with basic axioms; mathematical induction; set theory; applications of univariate and multivariate calculus.
- To introduce the student to probability. Topics to be covered will be chosen from: axiomatic development of probability; independence; Bayes theorem; discrete and continuous random variables; expectation; special distributions including the binomial and normal; moment generating functions; multi-variate distributions; conditional and marginal distributions; independence of random variables; transformations of random variables; limit theorems.

This course is designed primarily for Mathematical Sciences majors and those interested in the deeper mathematical issues underlying probability theory. A more applications-oriented course with similar content is MA 2621 Probability for Applications which is primarily designed for students in departments other than Mathematical Sciences.

Recommended background: Multivariable Differential and Integral Calculus (MA 1024, or equivalent).

Undergraduate credit may not be earned both for this course and for MA 2621 Probability for Applications.

MA 3212. ACTUARIAL MATHEMATICS I.
Cat. I
A study of actuarial mathematics with emphasis on the theory and application of contingency mathematics in various areas of insurance. Topics usually included are: survival functions and life tables; life insurance; property insurance; annuities; net premiums; and premium reserves.

Recommended background: An introduction to the theory of interest, and familiarity with basic probability (MA 2211 and either MA 2621 or MA 2631, or equivalent).

MA 3213. ACTUARIAL MATHEMATICS II.
Cat. I
A continuation of the study of actuarial mathematics with emphasis on calculations in various areas of insurance, based on multiple insureds, multiple decrements, and multiple state models. Topics usually included are: survival functions; life insurance; property insurance; common shock; Poisson processes and their application to insurance settings; gross premiums; and reserves.

Recommended background: An introduction to actuarial mathematics (MA 3212 or equivalent)

MA 3231. LINEAR PROGRAMMING.
Cat. I
The mathematical subject of linear programming deals with those problems in optimal resource allocation which can be modeled by a linear profit (or cost) function together with feasibility constraints expressible as linear inequalities. Such problems arise regularly in many industries, ranging from manufacturing to transportation, from the design of livestock diets to the construction of investment portfolios.

This course considers the formulation of such real-world optimization problems as linear programming problems, the most important algorithms for their solution, and techniques for their analysis. The core material includes problem formulation, the primal and dual simplex algorithms, and duality theory. Further topics may include: sensitivity analysis; applications such as matrix games or network flow models; bounded variable linear programs; interior point methods.

Recommended background: Matrices and Linear Algebra (MA 2071, or equivalent).

MA 3233. DISCRETE OPTIMIZATION.
Cat. II
Discrete optimization is a lively field of applied mathematics in which techniques from combinatorics, linear programming, and the theory of algorithms are used to solve optimization problems over discrete structures, such as networks or graphs. The course will emphasize algorithmic solutions to general problems, their complexity, and their application to real-world problems drawn from such areas as VLSI design, telecommunications, airline crew scheduling, and product distribution. Topics will be selected from: Network flow, optimal matching, integrality of polyhedra, matroids, and NP-completeness.

Recommended background: At least one course in graph theory, combinatorics or optimization (e.g., MA 2271, MA 2273 or MA 3231).

This course will be offered in 2020-21, and in alternating years thereafter.

MA 3257/CS 4032. NUMERICAL METHODS FOR LINEAR AND NONLINEAR SYSTEMS.
Cat. I
This course provides an introduction to modern computational methods for linear and nonlinear equations and systems and their applications.
Topics covered include: solution of nonlinear scalar equations, direct and iterative algorithms for the solution of systems of linear equations, solution of nonlinear systems, the eigenvalue problem for matrices. Error analysis will be emphasized throughout.
Recommended background: MA 2071. An ability to write computer programs in a scientific language is assumed.

MA 3457/CS 4033. NUMERICAL METHODS FOR CALCULUS AND DIFFERENTIAL EQUATIONS.
Cat. I
This course provides an introduction to modern computational methods for differential and integral calculus and differential equations.
Topics covered include: interpolation and polynomial approximation, approximation theory, numerical differentiation and integration, numerical solutions of ordinary differential equations. Error analysis will be emphasized throughout.
Recommended background: MA 2051. An ability to write computer programs in a scientific language is assumed. Undergraduate credit may not be earned for both this course and for MA 3255/CS 4031.

MA 3471. ADVANCED ORDINARY DIFFERENTIAL EQUATIONS.
Cat. II
The first part of the course will cover existence and uniqueness of solutions, continuous dependence of solutions on parameters and initial conditions, maximal interval of existence of solutions, Gronwall's inequality, linear systems and the variation of constants formula, Floquet theory, stability of linear and perturbed linear systems. The second part of the course will cover material selected by the instructor. Possible topics include: Introduction to dynamical systems, stability by Lyapunov's direct method, study of periodic solutions, singular perturbation theory and nonlinear oscillation theory.
Recommended background: MA 2431 and MA 3832.
This course will be offered in 2019-20, and in alternating years thereafter.

MA 3475. CALCULUS OF VARIATIONS.
Cat. II
This course covers the calculus of variations and select topics from optimal control theory. The purpose of the course is to expose students to mathematical concepts and techniques needed to handle various problems of design encountered in many fields, e. g. electrical engineering, structural mechanics and manufacturing.
Topics covered will include: derivation of the necessary conditions of a minimum for simple variational problems and problems with constraints, variational principles of mechanics and physics, direct methods of minimization of functions, Pontryagin's maximum principle in the theory of optimal control and elements of dynamic programming.
Recommended background: MA 2051.
This course will be offered in 2020-21, and in alternating years thereafter.

MA 3627. INTRODUCTION TO THE DESIGN AND ANALYSIS OF EXPERIMENTS.
Cat. II
This course will teach students how to design experiments in order to collect meaningful data for analysis and decision making. This course continues the exploration of statistics for scientific and industrial applications begun in MA 2611 and MA 2612. The course offers comprehensive coverage of the key elements of experimental design used by applied researchers to solve problems in the field, such as random assignment, replication, blocking, and confounding. Topics covered include the design and analysis of general factorial experiments; two-level factorial and fractional factorial experiments; principles of design; completely randomized designs and one-way analysis of variance (ANOVA); complete block designs and two-way analysis of variance; complete factorial experiments; fixed, random, and mixed models; split-plot designs; nested designs.
Recommended background: Applied Statistics (MA 2611 and MA2612, or equivalent).
This course will be offered in 2020-21, and in alternating years thereafter.

MA 3631. MATHEMATICAL STATISTICS.
Cat. I
This course introduces students to the mathematical principles of statistics. Topics will be chosen from: Sampling distributions, limit theorems, point and interval estimation, sufficiency, completeness, efficiency, consistency; the Rao-Blackwell theorem and the Cramer-Rao bound; minimum variance unbiased estimators and maximum likelihood estimators; tests of hypotheses including the Neyman-Pearson lemma, uniformly most powerful and likelihood radio tests.
Recommended background: MA 2631.

MA 3823. GROUP THEORY.
Cat. I
This course provides an introduction to one of the major areas of modern algebra. Topics covered include: groups, subgroups, permutation groups, normal subgroups, factor groups, homomorphisms, isomorphisms and the fundamental homomorphism theorem.
Recommended background: MA 2073.

MA 3825. RINGS AND FIELDS.
Cat. II
This course provides an introduction to one of the major areas of modern algebra. Topics covered include: rings, integral domains, ideals, quotient rings, ring homomorphisms, polynomial rings, polynomial factorization, extension fields and properties of finite fields. Recommended background: MA 2073.
This course will be offered in 2019-20, and in alternating years thereafter.

MA 3831. PRINCIPLES OF REAL ANALYSIS I.
Cat. I
Principles of Real Analysis is a two-part course giving a rigorous presentation of the important concepts of classical real analysis. Topics covered in the sequence include: basic set theory, elementary topology of Euclidean spaces, metric spaces, compactness, limits and continuity, differentiation, Riemann-Stieltjes integration, infinite series, sequences of functions, and topics in multivariate calculus.
Recommended background: at least one course focused on proof-based mathematics (e.g., MA 1971 Bridge to Higher Mathematics, MA 1033 Theoretical Calculus III).

MA 3832. PRINCIPLES OF REAL ANALYSIS II.
Cat. I
MA 3832 is a continuation of MA 3831. For the contents of this course, see the description given for MA 3831.
Recommended background: introductory knowledge in real analysis (e.g., MA 3831 Principles of Real Analysis I, or equivalent).

MA 4213. LOSS MODELS I – RISK THEORY.
Cat. I
This course covers topics in loss models and risk theory as it is applied, under specified assumptions, to insurance. Topics covered include: economics of insurance, short term individual risk models, single period and extended period collective loss models, and applications.
Recommended background: An introduction to probability (MA 2631 or equivalent).

MA 4214. LOSS MODELS II – SURVIVAL MODELS.
Cat. I
Survival models are statistical models of times to occurrence of some event. They are widely used in areas such as the life sciences and actuarial science (where they model such events as time to death, or to the development or recurrence of a disease), and engineering (where they model the reliability or useful life of products or processes). This course introduces the nature and properties of survival models, and considers techniques for estimation and testing of such models using realistic data. Topics covered will be chosen from: parametric and nonparametric survival models, censoring and truncation, nonparametric estimation (including confidence intervals and hypothesis testing) using right-, left-, and otherwise censored or truncated data.
Recommended background: An introduction to mathematical statistics (MA 3631 or equivalent).

MA 4216. ACTUARIAL SEMINAR.
Cat. I (0 credit)
This pass/fail graduation requirement will be offered every term, under the supervision of the actuarial professors. In order to receive a passing grade, students will need to complete some or all of the following: attend speaker talks, attend company visits to campus, take part and help out with Math Department activities, take part and help out with Actuarial Club activities, prepare for actuarial exams, or complete other activities as approved by the instructor(s).
Recommended background: Interest in being an actuarial mathematics major.

MA 4222. TOP ALGORITHMS IN APPLIED MATHEMATICS.
Cat. II
This course will introduce students to the top algorithms in applied mathematics. These algorithms have tremendous impact on the development and practice of modern science and engineering. Class discussions will focus on introducing students to the mathematical theory behind the algorithms as well as their applications. In particular, the course will address issues of computational efficiency, implementation, and error analysis. Algorithms to be considered may include the Krylov Subspace Methods, Fast Multipole Method, Monte Carlo Methods, Fast Fourier Transform, Kalman Filters and Singular Value Decomposition. Students will be expected to apply these algorithms to real-world problems; e.g., image processing and audio compression (Fast Fourier Transform), recommendation systems (Singular Value Decomposition), electromagnetics or fluid dynamics (Fast Multipole Method, Krylov Subspace Methods, and Fast Fourier Transform), and the tracking and prediction of an object's position (Kalman Filters). In addition to studying these algorithms, students will learn about high performance computing and will have access to a machine with parallel and GPU capabilities to run code for applications with large data sets.

Recommended background: Familiarity with matrix algebra and systems of equations (MA 2071, MA 2072, or equivalent), numerical methods for the solution of linear systems or differential equations (MA 3257, MA 3457, or equivalent), and concepts from probability (MA 2621, MA 2631, or equivalent). The ability to write computer programs in a scientific language is assumed.

This course will be offered in 2021-22, and in alternating years thereafter.

MA 4235. MATHEMATICAL OPTIMIZATION.
Cat. II
This course explores theoretical conditions for the existence of solutions and effective computational procedures to find these solutions for optimization problems involving nonlinear functions.

Topics covered include: classical optimization techniques, Lagrange multipliers and Kuhn-Tucker theory, duality in nonlinear programming, and algorithms for constrained and unconstrained problems.

Recommended background: Vector calculus at the level of MA 2251.

This course will be offered in 2019-20, and in alternating years thereafter.

MA 4237. PROBABILISTIC METHODS IN OPERATIONS RESEARCH.
Cat. II
This course develops probabilistic methods useful to planners and decision makers in such areas as strategic planning, service facilities design, and failure of complex systems.

Topics covered include: decisions theory, inventory theory, queuing theory, reliability theory, and simulation.

Recommended background: Probability theory at the level of MA 2621 or MA 2631.

This course will be offered in 2019-20, and in alternating years thereafter.

MA 4291. APPLIED COMPLEX VARIABLES.
Cat. I
This course provides an introduction to the ideas and techniques of complex analysis that are frequently used by scientists and engineers. The presentation will follow a middle ground between rigor and intuition.

Topics covered include: complex numbers, analytic functions, Taylor and Laurent expansions, Cauchy integral theorem, residue theory, and conformal mappings.

Recommended background: MA 1024 and MA 2051.

MA 4411. NUMERICAL ANALYSIS OF DIFFERENTIAL EQUATIONS.
Cat. II
This course is concerned with the development and analysis of numerical methods for differential equations.

Topics covered include: well-posedness of initial value problems, analysis of Euler's method, local and global truncation error, Runge-Kutta methods, higher order equations and systems of equations, convergence and stability analysis of one-step methods, multistep methods, methods for stiff differential equations and absolute stability, introduction to methods for partial differential equations.

Recommended background: MA 2071 and MA 3457/CS 4033. An ability to write computer programs in a scientific language is assumed.

This course will be offered in 2020-21, and in alternating years thereafter.

MA 4451. BOUNDARY VALUE PROBLEMS.
Cat. I
Science and engineering majors often encounter partial differential equations in the study of heat flow, vibrations, electric circuits and similar areas. Solution techniques for these types of problems will be emphasized in this course.

Topics covered include: derivation of partial differential equations as models of prototype problems in the areas mentioned above, Fourier Series, solution of linear partial differential equations by separation of variables, Fourier integrals and a study of Bessel functions.

Recommended background: MA 1024 or and MA 2051.

MA 4473. PARTIAL DIFFERENTIAL EQUATIONS.
Cat. II
The first part of the course will cover the following topics: classification of partial differential equations, solving single first order equations by the method of characteristics, solutions of Laplace's and Poisson's equations including the construction of Green's function, solutions of the heat equation including the construction of the fundamental solution, maximum principles for elliptic and parabolic equations. For the second part of the course, the instructor may choose to expand on any one of the above topics.

Recommended background: MA 2251 and MA 3832.

This course will be offered in 2020-21, and in alternating years thereafter.

MA 4603/BCB 4004. STATISTICAL METHODS IN GENETICS AND BIOINFORMATICS.
Cat. II
This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees.

Recommended background: MA 2612, MA 2631 (or MA 2621), and BB 2920.

This course will be offered in 2019-20, and in alternating years thereafter.

MA 4631. PROBABILITY AND MATHEMATICAL STATISTICS I.
Cat. I (14 week course)
Intended for advanced undergraduates and beginning graduate students in the mathematical sciences and for others intending to pursue the mathematical study of probability and statistics, this course begins by covering the material of MA 3613 at a more advanced level. Additional topics covered are: one-to-one and many-to-one transformations of random variables; sampling distributions; order statistics, limit theorems.

Recommended background: MA 2631 or MA 3613, MA 3831, MA 3832.

MA 4632. PROBABILITY AND MATHEMATICAL STATISTICS II.
Cat. I (14 week course)
This course is designed to complement MA 4631 and provide background in principles of statistics.

Topics covered include: point and interval estimation; sufficiency, completeness, efficiency, consistency; the Rao-Blackwell theorem and the Cramer-Rao bound; minimum variance unbiased estimators, maximum likelihood estimators and Bayes estimators; tests of hypothesis including uniformly most powerful, likelihood ratio, minimax and bayesian tests.

Recommended background: MA 3631 or MA 4631.

MA 4635. DATA ANALYTICS AND STATISTICAL LEARNING.
Cat. I
The focus of this class will be on statistical learning – the intersection of applied statistics and modeling techniques used to analyze and to make predictions and inferences from complex real-world data. Topics covered include: regression; classification/clustering; sampling methods (bootstrap and cross validation); and decision tree learning.

Students may not receive credit for both MA 463X and MA 4635.

Recommended background: Linear Algebra (MA 2071 or equivalent), Applied Statistics and Regression (MA 2612 or equivalent), Probability (MA 2631 or equivalent). The ability to write computer programs in a scientific language is assumed.

MA 4891. TOPICS IN MATHEMATICS.
Cat. I

MA 4892. TOPICS IN ACTUARIAL MATHEMATICS.
Cat. II
Topics covered in this course would vary from one offering to the next. The purpose of this course will be to introduce actuarial topics that typically arise in the professional actuarial organization's curriculum beyond the point where aspiring actuaries are still in college. Topics might include ratemaking, estimation of unpaid claims, equity linked insurance products, simulation, or stochastic modeling of insurance products.

Recommended background: Could vary by the specific topics being covered, but would typically include an introduction to the theory of interest and an introduction to actuarial mathematics (MA 2211 and MA 3212 or equivalent).

This course will be offered in 2020-21, and in alternating years thereafter.

MA 4895. DIFFERENTIAL GEOMETRY.
Cat. II
The course gives an introduction to differential geometry with a focus on Riemannian geometry. Starting with the geometry of curves and surfaces in the three-dimensional Euclidean space and Riemannian metrics in 2 and higher dimensions, the course introduces the first fundamental form, tangent bundles, vector fields, distance functions and geodesics, followed by covariant derivatives and second fundamental form. The proof of Gauss's Theorema Egregium is highlighted. Additional topics are by instructor's discretion. Students may not receive credit for both MA 489X and MA 4895.

Recommended background: Advanced Linear Algebra and Real Analysis (e.g., MA 2073 Theoretical Linear Algebra and MA 3831 Principles of Real Analysis, or equivalent)

MECHANICAL ENGINEERING

The second digit in mechanical engineering course numbers is coded as follows:

0 — General mechanical engineering
1 —
2 —
3 — Design
4 — Thermal—fluids
5 — Engineering mechanics
6 — Fluid mechanics—hydraulics
7 — Aerospace
8 — Materials
9 — Engineering experimentation

ME 1520. THE TECHNOLOGY OF ALPINE SKIING.
Cat. II
This course explores science and engineering issues associated with equipment and technique for alpine skiing, particularly racing. A diverse group of technical subjects related to engineering mechanics are discussed: tribology, beams, rigid body motion, material science, machining and biomechanics. Specifically we will examine: ski-snow interactions, technique for gliding, turning and stepping, selection of line in racing; equipment design, testing and performance; and ski injuries. We will also address issues in the epidemiology of skiing injuries, the calculation of the cost of ski injuries to society, the impact of ski equipment technology on litigation and the impact of litigation on equipment and trail design.

This course will be offered in 2020-21, and in alternating years thereafter.

ME 1800. MANUFACTURING SCIENCE, PROTOTYPING, AND COMPUTER-CONTROLLED MACHINING.
Cat. I
This course introduces students to manufacturing science and engineering and prototype part production. It emphasizes CNC (computer-controlled) machining. Students will learn how to go from a solid (CAD, computer-aided design) model to a machined part, using CAM software (computer-aided manufacturing) and CNC machining. They will also be exposed to associated issues in manufacturing process analysis, engineering design, material science, and in dimensional and surface metrology. Using machining as an example, the science of manufacturing processes is developed in a combination of class work and laboratory experience. The laboratory experience includes an experimental component that relates process variables in machining with performance and machined part quality. Students whose project work will necessitate fabrication of parts and those who want a background in manufacturing process science and engineering should take this course.

ME 2300. INTRODUCTION TO ENGINEERING DESIGN.
Cat. I
This project based course introduces students to the engineering design process including; identifying the need, benchmarking, writing design specifications, evaluating alternative designs and selecting a final design. Student groups will construct and evaluate a working prototype of their design. Additional topics include; creativity, product liability, reverse engineering, patents, and codes of ethics for engineers. Extensive written reports and oral presentations are required.

Recommended background: computer-aided design (ES 1310), mechanics (ES 2501, ES 2502), and manufacturing (ME 1800).

ME/CHE 2301. NANOBIOTECHNOLOGY LABORATORY EXPERIENCE.
Cat. II
The current developments and experimental skills in nanoscale bioscience and biotechnology will be introduced. Experimental skills such as nanomaterials synthesis, electron microscopy and introductory biotechnology techniques are presented. This course will provide students training in laboratory technique and data handling.

Recommended background: CH 1010 or equivalent.

This course will be offered in 2020-21, and in alternating years thereafter.

ME 2312. INTRODUCTION TO COMPUTATIONAL SOLUTIONS FOR ENGINEERING PROBLEMS.
Cat. I
The purpose of this course is to introduce concepts of programming and numerical methods using Matlab within an engineering framework. The course will review basic linear algebra, statics, stress analysis, and engineering governing equations with solution pathways developed and presented as numerical programming problems. The fundamental programming techniques cover a variety of input and output formats typically encountered in engineering situations. Control and conditional loops, recognizing and controlling numerical error, numerical integration and differentiation will be introduced and developed within an engineering framework.

Recommended background: Statics (ES 2501), Stress Analysis (ES 2502), General Physics-Mechanics (PH 1110), Differential and Integral Calculus (MA 1021, MA 1022) or equivalents.

ME 2820. MATERIALS PROCESSING.
Cat. I
An introduction to material processing in manufacturing. This course provides important background for anyone interested in manufacturing, design engineering design, sales, or management.

Processing of polymers, ceramics, metals and composites is discussed. Processes covered include: rolling, injection molding, forging, powder metallurgy, joining and machining. The relationships between materials, processes, processing parameters and the properties of manufactured parts are developed. During the course the students should develop the ability to choose materials, processes, and processing parameters for designing manufacturing procedures to take a prototype part to production.

Recommended background: ME 1800 Materials Selection and Manufacturing Processes, and ES 2001 Introduction to Materials Science.

ME 3310. KINEMATICS OF MECHANISMS.
Cat. I
An introduction to the synthesis and analysis of linkages, cams and gear trains is presented. The design process is introduced and used to solve unstructured design problems in linkage and cam design. Algebraic and graphical techniques to analyze the displacement, velocity and acceleration of linkages and cams are developed. Computer programs for the design and analysis of linkages are used by students. Results of student design projects are presented in professional engineering reports.

Recommended background: Ordinary Differential Equations (MA 2051), statics (ES 2501), dynamics (ES 2503).

ME 3311. DYNAMICS OF MECHANISMS AND MACHINES.
Cat. II
This course provides an in-depth study of forces in dynamic systems. Dynamic force analysis is developed using matrix methods. Computer programs are used to solve the sets of simultaneous equations derived by students for realistic, unstructured design problems. Inertial and shaking forces, elementary mechanical vibrations, torque-time functions, rotational and reciprocating balance and cam dynamics are covered using the internal combustion engine as a

design example. Students execute unstructured design projects and prepare professional engineering reports on the results. Computers are used extensively to solve the dynamic equations.

Recommended background: Ordinary Differential Equations (MA 2051), statics (ES 2501), dynamics (ES 2503), kinematics (ME 3310), linear algebra.

This course will be offered in 2020-21, and in alternating years thereafter.

ME 3320. DESIGN OF MACHINE ELEMENTS.
Cat. I
This is an introductory course in mechanical design analysis, and it examines stress and fatigue in many machine elements. Common machine elements are studied and methods of selection and design are related to the associated hardware.

Topics covered include: combined stresses, fatigue analysis, design of shafts, springs, gears, bearings and miscellaneous machine elements.

Recommended background: mechanics (ES 2501, ES 2502, ES 2503), materials (ME 1800, ME 2820), computer programming (CS 1101 or CS 1102).

ME 3411. INTERMEDIATE FLUID MECHANICS.
Cat. I
This course provides a mixture of theory and applications and covers topics not found in the introductory course in fluid mechanics. Topics include kinematics of fluid flow, potential flow, Navier-Stokes and the theory of viscous flow, basic turbulence, boundary layer theory, and introduction to compressible flow.

Recommended background: Introductory fluid mechanics (ES 3004, or equivalent).

ME 3501. ELEMENTARY CONTINUUM MECHANICS.
Cat. II
In typical mathematics courses, students learn principles and techniques by solving many short and specially prepared problems. They rarely gain experience in formulating and solving mathematical equations that apply to real life engineering problems. This course will give students this type of applied mathematical experience.

The course emphasizes the application of basic laws of nature as they apply to differential elements which lead to differential equations that need to be solved; all of these ideas are used in higher level engineering science courses such as fluid mechanics, heat transfer, elasticity, etc. Emphasis will be placed on understanding the physical concepts in a problem, selecting appropriate differential elements, developing differential equations, and finding ways to solve these equations. Limitations on the mathematical solutions due to assumptions made will be considered.

Recommended background: Ordinary Differential Equations (MA 2051), statics (ES 2501), dynamics (ES 2503).

This course will be offered in 2020-21, and in alternating years thereafter.

ME 3506. REHABILITATION ENGINEERING.
Cat. I
This project based design course focuses on the design and use of devices to aid persons with disabilities. Human factors and ergonomics are integrated into all phases of the design process with particular emphasis on the user interface.

Topics include: defining the problem, developing design specifications, development of preliminary designs, selection, realization and evaluation of a final design. Students will also learn how physical, and cognitive parameters, safety, economics, reliability and aesthetics need to be incorporated into the design process.

Recommended background: mechanics (ES 2501, ES 2502, ES 2503), design (ME 2300), materials (ME 1800) and electrical engineering (ECE 2010).

ME 3820. COMPUTER-AIDED MANUFACTURING.
Cat. I
This introductory course in modern control systems will give students an understanding of the basic techniques, and the range of equipment used in most computer controlled manufacturing operations. The class work is reinforced by hands-on laboratories in the Robotics/CAM lab. Modeling and analysis of machining processes, and applications of PLC (programmable logic control) are included.

Class topics include: Manufacturing Automation, Microcomputers for Process Monitoring and Control, Computer Numerical Control, Switching Theory and Ladder Logic, Transducers and Signal Conditioning, and Closed Loop Digital Control. The laboratories allow students to program and implement several types of the controllers, and will provide an introduction to the topic of industrial robotics.

Recommended background: manufacturing (ME 1800), materials processing (ME 2820), elementary computer/logic device programming.

ME 3901. ENGINEERING EXPERIMENTATION.
Cat. I
A course designed to develop analytical and experimental skills in modern engineering measurement methods, based on electronic instrumentation and computer-based data acquisition systems. The lectures are concerned with the engineering analysis and design as well as the principles of instrumentation, whereas the laboratory periods afford the student an opportunity to use modern devices in actual experiments.

Lecture topics include: review of engineering fundamentals and, among others, discussions of standards, measurement and sensing devices, experiment planning, data acquisition, analysis of experimental data, and report writing.

Laboratory experiments address both mechanical and thermal systems and instrumentation in either traditional mechanical engineering (heat transfer, flow measurement/visualization, force/torque/strain measurement, motion/vibration measurement) or materials engineering (temperature and pressure measurements in materials processing, measurement of strain and position in mechanical testing of materials). Each year students will be notified which type of experiments will be used in each term offering. Students may also consult with their academic advisor or the Mechanical Engineering department office.

Recommended background: mathematics (MA 2051), thermo-fluids (ES 3001, ES 3003, ES 3004), mechanics (ES 2501, ES 2502, ES 2503), materials (ES 2001).

ME 3902. PROJECT-BASED ENGINEERING EXPERIMENTATION.
Cat. I
This course is designed to develop experimental skills in engineering measurement methods, based on electronic instrumentation and computer-based data acquisition systems, such as the Raspberry Pi (a primarily digital microprocessor) and an Arduino (a primarily analog microcontroller). The lectures are concerned with the engineering design requirements as well as the principles of instrumentation, whereas the laboratory modules afford the student an opportunity to use these devices in actual experiments. Lecture topics include: discussions of standards, measurement and sensing devices, experiment planning, data acquisition, analysis of experimental data, and report writing. Laboratory experiments address mechanical (force/torque/strain measurements, motion/vibration measurements), energy (heat transfer, temperature, flow measurements), materials measurements (materials processing, measurement of strain and position in mechanical testing of materials), and instrumentation. The course culminates with an open-ended project of the students choosing. This open-ended project will illuminate the skills gained by the student to utilize multiple sensors and equipment to monitor and/or control physical situations.

Recommended background: introductory heat transfer (ES3003 or equivalent), introductory stress and dynamic mechanics (ES 2502 & ES 2503 or equivalents), introductory electrical and computer engineering (ES2010 or equivalent) and introductory materials (such as ES 2001 or equivalent).

ME 4320. ADVANCED ENGINEERING DESIGN.
Cat. I
This course integrates students' background in ME in a one-term design project that is usually taken from a local company. Students must organize themselves and the project to successfully realize a product that meets customer needs. Activities include problem definition, design analysis, mathematical modelling, CAD modelling, manufacturing, testing, liaison to vendors, customer relations, marketing, technical management, purchasing, report writing, and oral presentations.

Recommended background: mechanisms (ME 3310, ME 3311), stress analysis (ES 3502), design (ME 3320), thermo-fluids (ES 3001, ES 3003, ES 3004), materials (ES 2001), manufacturing (ME 1800).

ME/RBE 4322. MODELING AND ANALYSIS OF MECHATRONIC SYSTEMS.
Cat. I
This course introduces students to the modeling and analysis of mechatronic systems. Creation of dynamic models and analysis of model response using the bond graph modeling language are emphasized. Lecture topics include energy storage and dissipation elements, transducers, transformers, formulation of equations for dynamic systems, time response of linear systems, and system control through open and closed feedback loops. Computers are used extensively for system modeling, analysis, and control. Hands-on projects will include the reverse engineering and modeling of various physical systems. Physical models may sometimes also be built and tested.

Recommended background: mathematics (MA 2051, MA 2071), fluids (ES 3004), thermodynamics (ES 3001), mechanics (ES 2501, ES 2503)

ME 4422. DESIGN AND OPTIMIZATION OF THERMAL SYSTEMS.
Cat. I
This course introduces students to design of small and large scale optimal thermal systems. The hardware associated with thermal systems includes fans, pumps, compressors, engines, expanders, turbines, heat and mass exchangers, and reactors, all interconnected with some form of conduits. Generally, the working substances are fluids. These types of systems appear in such industries as power generation, electric and gas utilities, refrigeration and cryogenics, air conditioning and heating, food, chemical, petroleum, and other process industries.

This course is intended for mechanical engineering students, especially those seeking a concentration in Thermal-Fluids. Additionally, this course might be of interest to students in Aerospace Engineering and Chemical Engineering.

Recommended Background: Knowledge in thermodynamics (ES 3001), fluid mechanics (ES 3004), heat transfer (ES 3003), and introduction to design (ME 2300)

ME 4424. RADIATION HEAT TRANSFER APPLICATION AND DESIGN.
Cat. II
Radiation Heat Transfer Applications will develop the student's knowledge of radiation and multi-mode heat transfer. Fundamentals of radiation will be covered: radiative properties of surfaces; view factors; exchange between black and grey surfaces; emission and absorption of gases; and flame radiation. Use of numerical methods will be emphasized as appropriate for solution of applications: the select numerical methods (numerical integration, matrix methods, ODE solutions) can be learned during the course. The course will conclude with a design exercise to be completed by each student. Each exercise will highlight radiation in a realistic scenario that requires multi-mode heat transfer and fluid mechanics analysis to develop the design solution. Exercise topics will come from subjects such as: solar power plants, solar effects on buildings, furnaces, fire safety in the built environment, etc.

Recommended background: differential and integral calculus, and ordinary differential equations (MA 2051 or equivalent), and thermodynamics, fluid mechanics and heat transfer (ES 3001, 3004, 3003 or equivalents).

Students may not receive credit for both ME 4424 and ME 442X.

This course will be offered in 2020-21, and in alternating years thereafter.

ME 4429. THERMOFLUID APPLICATION AND DESIGN.
Cat. I
This course integrates thermodynamics, fluid mechanics and heat transfer through the use of design projects involving modern technologies, such as electronic cooling, vapor compression power and refrigeration cycles. Activities include problem definition, design creation and analysis, mathematical modeling, cost analysis and optimization.

Recommended background: knowledge in thermodynamics, fluid mechanics, heat transfer and introduction to design (ES 3001, ES 3004 and ES 3003, ME 2300 or equivalent).

ME 4430. INTEGRATED THERMOMECHANICAL DESIGN AND ANALYSIS.
Cat. II
Current state-of-the-art computer based methodologies used in the design and analysis of thermomechanical systems will be presented and illustrated by selected laboratory demonstrations, and used in projects. Projects will include thermal, mechanical, electronic, and photonic loads of steady state and dynamic nature and will integrate design, analysis, and testing. Students will prepare a technical report and present their results. Topics will include, but not be limited to, thermomechanics of fiber optic telecommunication cables, high-energy beam interactions with materials, shape memory alloys, microelectronics, MEMS and mechatronics.

Recommended background: MA 2051, ES 2001, ES 2502, ES 3003, ME 3901, and an introduction to design.

This course will be offered in 2020-21, and in alternating years thereafter.

ME/BME 4504. BIOMECHANICS.
Cat. II
This course emphasizes the applications of mechanics to describe the material properties of living tissues. It is concerned with the description and measurements of these properties as related to their physiological functions. Emphasis on the interrelationship between biomechanics and physiology in medicine, surgery, body injury and prostheses.

Topics covered include: review of basic mechanics, stress, strain, constitutive equations and the field equations, viscoelastic behavior, and models of material behavior. The measurement and characterization of properties of tendons, skin, muscles and bone. Biomechanics as related to body injury and the design of prosthetic devices.

Recommended background: mechanics (ES 2501, ES 2502, ES 2503, ME 3501), mathematics (MA 2051).

This course will be offered in 2019-20, and in alternating years thereafter.

ME 4506. MECHANICAL VIBRATIONS.
Cat. I
This course is an introduction to the fundamental concepts of mechanical vibrations, which are important for design and analysis of mechanical and structural systems subjected to time-varying loads. The objective of the course is to expose the students to mathematical modeling and analysis of such systems

Topics covered include: formulation of the equations of motion using Newton's Laws, D'Alembert's Principle and energy methods; prediction of natural frequency for single-degree-of-freedom systems; modeling stiffness characteristics, damping and other vibrational properties of mechanical systems; basic solution techniques by frequency response analysis and convolution integral methods. Examples may include analysis and design for transient passage through resonance; analysis and design of vibration measurement devices; introductory rotordynamics. The course is mainly focused on analysis of single-degree-of-freedom systems, however a basic introduction into multidegree-of-freedom systems is also presented. Computer-based project may be suggested.

Recommended background: Ordinary Differential Equations (MA 2501), Statics (ES 2501), Dynamics (ES 2503).

ME 4512. INTRODUCTION TO THE FINITE ELEMENT METHOD.
Cat. I
This course serves as an introduction to finite element analysis (FEA) for stress analysis problems. Finite element equations are developed for several element types from stiffness and energy approaches and used to solve simple problems. Element types considered include spring, truss, beam, two-dimensional (plane stress/strain and axisymmetric solid), three-dimensional and plates. Stress concentrations, static failures, and fatigue failures are considered for each element type. Emphasis will be placed on knowing the behavior and usage of each element type, being able to select a suitable finite element model for a given problem, and being able to interpret and evaluate the solution quality. A commercial, general-purpose finite element computer program is used to solve problems that are more complex. Projects are used to introduce the use of FEA in the iterative design process.

Recommended background: Mathematics (MA 2051, MA 2071), Mechanics (ES 2501 & ES 2502 or CE 2000 & CE 2001).

ME/BME 4606. BIOFLUIDS.
Cat. II
This course emphasizes the applications of fluid mechanics to biological problems. The course concentrates primarily on the human circulatory and respiratory systems. Topics covered include: blood flow in the heart, arteries, veins and microcirculation and air flow in the lungs and airways. Mass transfer across the walls of these systems is also presented.

Recommended background: continuum mechanics (ME 3501), fluids (ES 3004).

This course will be offered in 2020-21, and in alternating years thereafter.

ME 4718. ADVANCED MATERIALS WITH AEROSPACE APPLICATIONS.
Cat. I
This course covers topics on the design, fabrication and behavior of advanced materials used in structural and propulsion components of aerospace vehicles. The design, fabrication, and properties of polymer, metal and ceramic matrix composites used in aerospace structures are presented. The fabrication and behavior of aluminum and titanium alloys used in propulsion components as well as the processing and performance of Nickel-based superalloys are also presented. The fundamentals of coatings for high temperature oxidation, hot corrosion, and thermal protection are introduced.

Recommended background: Introduction to Materials Science (ES 2001), Stress Analysis (ES 2502) or equivalent.

ME 4810. AUTOMOTIVE MATERIALS AND PROCESS DESIGN.
Cat. II
This course focuses on materials used in the automotive industry. Students complete a term-long project that integrates design, materials selection and processing considerations. Activities include: problem definition, development of design specifications, development and analysis of alternative designs, conceptual designs and materials and process selection. Students will consider cost, and environmental impact of alternative material choices. Students will present their results in intermediate and final design reviews.

Recommended background: materials science (ES 2001), stress analysis (ES 2502), or equivalent.

This course will be offered in 2019-20, and in alternating years thereafter.

ME 4813. CERAMICS AND GLASSES FOR ENGINEERING APPLICATIONS.
Cat. II
This course develops an understanding of the processing, structure, property, performance relationships in crystalline and vitreous ceramics. The topics covered include crystal structure, glassy structure, phase diagrams, microstructures, mechanical properties, optical properties, thermal properties, and materials selection for ceramic materials. In addition the methods for processing ceramics for a variety of products will be included.
Recommended Background: ES 2001 or equivalent.
This course will be offered in 2019-20, and in alternating years thereafter.

ME/BME 4814. BIOMATERIALS.
Cat. I
A course specializing in material selection and special problems associated with biomedical engineering.
Topics covered include: fundamentals of metals, plastics, and ceramics and how they can be applied to biomedical applications. Case histories of successful and unsuccessful material selections. Current literature is the primary source of material.
Recommended background: materials (ES 2001).

ME/RBE 4815. INDUSTRIAL ROBOTICS.
Cat. I
This course introduces students to robotics within manufacturing systems. Topics include: classification of robots, robot kinematics, motion generation and transmission, end effectors, motion accuracy, sensors, safety systems, robot control and automation. This course is a combination of lecture, laboratory and project work, and utilizes industrial robots. Through the laboratory work, students will become familiar with robotic programming (using a robotic programming language RAPID) and the robotic teaching mode. The experimental component of the laboratory exercise measures the motion and positioning capabilities of robots as a function of several robotic variables and levels, and it includes the use of experimental design techniques.
Recommended background: manufacturing (ME 1800), kinematics (ME 3310), control (ES 3011), and computer programming.

ME 4821. PLASTICS.
Cat. II
This course develops the processing, structure, property, performance relationships in plastic materials. The topics covered include polymerization processes, chain structure and configuration, molecular weights and distributions, amorphous and crystalline states and glass-rubber transition. The principles of various processing techniques including injection molding, extrusion, blow molding, thermoforming and calendaring will be discussed. The physical and mechanical properties of polymers and polymer melts will be described with specific attention to rheology and viscoelasticity. Pertinent issues related to environmental degradation and recyclability will be highlighted.
Recommended Background: ES 2001 or equivalent.
This course will be offered in 2019-20, and in alternating years thereafter.

ME 4832. CORROSION AND CORROSION CONTROL.
Cat. II
An introductory course designed to acquaint the student with the different forms of corrosion and the fundamentals of oxidation and electro-chemical corrosion.
Topics covered include: corrosion principles, environmental effects, metallurgical aspects, galvanic corrosion, crevice corrosion, pitting, intergranular corrosion, erosion corrosion, stress corrosion, cracking and hydrogen embrittlement, corrosion testing, corrosion prevention, oxidation and other high-temperature metal-gas reactions.
Recommended background: materials (ES 2001).
This course will be offered in 2019-20, and in alternating years thereafter.

ME 4840. PHYSICAL METALLURGY.
Cat. I
Fundamental relationships between the structure and properties of engineering materials are studied. Principles of diffusion and phase transformation are applied to the strengthening of commercial alloy systems. Role of crystal lattice defects on material properties and fracture are presented.
Strongly recommended as a senior-graduate level course for students interested in pursuing a graduate program in materials or materials engineering at WPI, or other schools.
Recommended background: materials (ES 2001, ME 2820).

ME 4875/MTE 575. INTRODUCTION TO NANOMATERIALS AND NANOTECHNOLOGY.
Cat. I
This course introduces students to current developments in nanoscale science and technology. The current advance of materials and devices constituting of building blocks of metals, semiconductors, ceramics or polymers that are nanometer size (1-100 nm) are reviewed. The profound implications for technology and science of this research field are discussed. The differences of the properties of matter on the nanometer scale from those on the macroscopic scale due to the size confinement, predominance of interfacial phenomena and quantum mechanics are studied. The main issues and techniques relevant to science and technologies on the nanometer scale are considered. New developments in this field and future perspectives are presented. Topics covered include: fabrication of nanoscale structures, characterization at nanoscale, molecular electronics, nanoscale mechanics, new architecture, nano-optics and societal impacts.
Recommended background: ES 2001 Introduction to Materials or equivalent
Some sections of this course may be offered as Writing Intensive (WI).

ISU. SPECIAL TOPICS.
Cat. I
For students who wish to pursue in depth various mechanical engineering topics.
Topics covered include: theoretical or experimental studies in subjects of interest to mechanical engineers.
Registration as a junior or senior is assumed.

MILITARY SCIENCE

ML 1011. FOUNDATIONS OF OFFICERSHIP I.
Cat. I (0 units w/grade)
Introduction to issues and competencies that are central to a commissioned officer's responsibilities. Establishes a framework for understanding officership, leadership, and Army values. Additionally, the semester addresses "life skills" including fitness and time management. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.

ML 1012. FOUNDATIONS OF OFFICERSHIP II.
Cat. I (1/9 unit after completion of 1011 and 1012)
This course continues the studies begun in ML 1011. Students make oral presentations on the elements of leadership, enhancing effective communication. Students begin to develop leadership potential by instilling self-confidence and fostering teamwork through basic survival techniques (e.g., water survival). Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.

ML 1021. BASIC LEADERSHIP I.
Cat. I (0 units w/grade)
ML 1021 expands upon the fundamentals introduced in the previous term by focusing on communications, leadership, and problem solving. "Life skills" lessons in this semester include: problem solving, goal setting, interpersonal communication skills, and assertiveness skills. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.

ML 1022. BASIC LEADERSHIP II.
Cat. I (1/9 unit after completion of 1021 and 1022)
ML 1022 continues by providing cadets with interesting lessons yielding immediately useful skills. The course also gives accurate information about life in the Army, including the organization of the Army, employment benefits, and work experiences of junior officers. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.

ML 2011. INDIVIDUAL LEADERSHIP STUDIES I.
Cat. I (1/12 unit)
Introduces students to team building techniques. Students build upon the basic leader principals and leadership development methodologies to refine their understanding of leadership. How to build teams, how to influence, how to communicate, how and when to make decision, and creative problem-solving. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 1022

ML 2012. INDIVIDUAL LEADERSHIP STUDIES II.
Cat. I (1/12 unit)
The curriculum focuses on building character. Where years one, three and four focus on mastering definitions, concepts, ideas and principles, year two focuses on direct, physical experiences. Year two centers on giving cadets the opportunity to apply, practice and experience leadership principles. Cadets are asked to reflect upon their actions and those of others. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 2011

ML 2021. LEADERSHIP AND TEAMWORK I.
Cat. I (1/12 unit)
Students continue the study of leader principals and are introduced to formal policies such as equal opportunity, ethics, and values. Military communication skills are trained along with the principles of camouflage. Complex cases of risk management are studied. Students will submit a written information paper. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 2012

ML 2022. LEADERSHIP AND TEAMWORK II.
Cat. I (1/12 unit)
This course covers small unit movement and military tactics. It combines previous study in weapons, movement and communications to teach the combination of firepower and maneuver to the student. This course also teaches the student the elements of how the military trains its personnel. A written decision paper and practical exercise in conducting training is included in this course. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 2021

ML 3011. LEADERSHIP AND PROBLEM SOLVING I.
Cat. I (1/6 unit)
This course focuses on development of individual leadership abilities. This course reviews leadership styles, management strategies and training techniques for leaders of small units. Promoting and developing communication skills and teamwork are addressed. Examines leadership of small units conducting conventional combat operations and tactical employment of weapon systems. Development of oral communication skills through military briefings and issuance of operations orders. Special attention is placed on evaluations through practical exercises. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required. Recommended background: Students must have completed the basic course or ROTC Leadership Training course and have signed a personal contract with the US Army. Department Head approval is required.

ML 3012. LEADERSHIP AND PROBLEM SOLVING II.
Cat. I (1/6 unit)
Student learns how to conduct crisis planning and management. Discussion of roles and functions of combat arms, combat support, and combat service support branches. Case studies of small-unit operations are studied. Introduction to Army special operations, military operations other than war, and trends in the military. Students write self-evaluations throughout this course. Students are graded on their performance during leadership practical exercises. Attendance at monthly labs and formal social functions is required. Students write self-evaluations through this course. Students are graded on their performance during leadership practical exercises. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 3011

ML 3021. LEADERSHIP AND ETHICS I.
Cat. I (1/6 unit)
ML 3021 is designed to continue the development as leaders by presenting instruction in the three foundational areas of leadership, interpersonal communication, and values and ethics. The leadership module contains an examination of Army leadership doctrine followed by expansion on key leadership concepts and provide feedback for cadet leadership self-development efforts. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.

ML 3022. LEADERSHIP AND ETHICS II.
Cat. I (1/6 unit)
The main thrust of the communication module is the opportunity for cadets to present an information briefing and receive feedback from both instructor and fellow students. The last module of the term contains lessons that focus on values, ethics, ethical decision-making, consideration of others, and spiritual needs. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 3021

ML 4011. LEADERSHIP AND MANAGEMENT I.
Cat. I (1/6 unit)
ML 4011 begins with a series of lessons designed to enable the cadets to make informed career decisions as they prepare their accessions documents. Lessons concentrate on Army operations and training management, communications and leadership skills and support the beginning of the final transition from cadet to lieutenant. The course focuses cadets, early in the year, on attaining knowledge and proficiency in several critical areas they will need to operate effectively as Army officers. These areas include: the Army's training management system, coordinating activities with staffs, and counseling skills. While the proficiency attained in each of these areas will initially be at the apprentice level, cadets will continue to sharpen these skills as they perform their roles as cadet officers in the ROTC battalion and as new lieutenants after commissioning. At the end of this semester cadets should possess the fundamental skills, attributes, and abilities to operate as competent leaders in the cadet battalion and confidently shoulder the responsibilities entrusted to them. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.

ML 4022. LEADERSHIP AND MANAGEMENT II.
Cat. I (1/6 unit)
This Course focuses on completing the transition from cadet to lieutenant. As an expansion of the Ethics instruction in ML 3021, the course starts with an examination of unit ethical climate and the commander's role as the moral anchor of the unit. This is followed by a module addressing military law and leadership. The next module reinforces previous instruction on the organization of the Army and introduces how the Army organizes for operations from the tactical to strategic level. This is followed by instruction on administrative and logistical management that focuses on the fundamentals of soldier and unit level support. Next is a short module that focuses on preparing cadets for their forthcoming commissioning and military service. At the core of this semester is the Advanced Course's Capstone Exercise. This twelve-lesson exercise directly reinforces all modules from this term, and also incorporates and reinforces many learning objectives from modules throughout the entire curriculum. The Capstone Exercise requires cadets, both individually and collectively, to apply their knowledge to solve problems and confront situations commonly faced by junior officers. Upon completion of this course the cadets will be prepared to shoulder the responsibility of being a commissioned officer in the United States Army. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises, Military Staff Ride and other special events is required.

ML 4023. OFFICERSHIP.
Cat. I (1/6 unit)
This course is a continuation of ML 4022.

ML 4024. TRANSITION TO LIEUTENANT.
Cat. I (1/6 unit)
Cadets organize and lead all the junior cadets. This course covers the military legal system, personnel actions and personal finances. It certifies fundamental competencies in land navigation, tactics, counseling, and interpersonal communications. This course requires three hours of class work and three hours of physical fitness per week. Participation in weekly training leadership laboratories; off campus training sessions (field training exercises) and other special events is required.
Recommended background: ML 4023

PHYSICAL EDUCATION

GENERAL PHYSICAL EDUCATION COURSES

PE 1002. INTRO TO VOLLEYBALL & SQUASH.
Cat. I (1/12 unit)
Introduction to the sports through skill development and play.

PE 1003. INTRODUCTION TO BADMINTON.
Cat. I (1/12 unit)
Introduction to the sport through skill development and play.

PE 1006. WELLNESS.
Cat. I (1/12 unit)
Introductory course designed to acquaint students with knowledge and skills necessary to make choices that foster health and well-being.

PE 1007. BASIC WATER SAFETY.
Cat. I (1/12 unit)
For the intermediate to advanced swimmer only. Students will learn about water recreational activities and how to remain safe while participating in them. Opportunity to learn the necessary means for safety in/near water and basic rescue techniques.

PE 1008. ROWING FOR FITNESS.
Cat. I
This course will teach basic rowing training techniques and principles with the goal for students to develop and implement an individualized conditioning program for themselves. All classes will be conducted on-campus through the use of rowing machines located in the Sports and Recreation Center.

PE 1009. WALKING FOR FITNESS.
Cat. I
This course will teach basic walking techniques and principles with the goal for students to develop and implement an individualized conditioning program for themselves.

PE 1011. TOUCH FOOTBALL.
Cat. I (1/12 unit)
Introduction to basic rules and individual/team skill development with practical application through game competition.

PE 1012. BASKETBALL.
Cat. I (1/12 unit)
Introduction to basic rules and individual/team skill development with practical application through game competition.

PE 1013. SOFTBALL.
Cat. I (1/12 unit)
Introduction to basic rules and individual/team skill development with practical application through game competition.

PE 1015. BADMINTON & TABLE TENNIS.
Cat. I (1/12 unit)
Instruction will focus on basic strokes and techniques. Rules, strategy and play will be integrated as students' skills develop.

PE 1016. SQUASH & RACQUETBALL.
Cat. I (1/12 unit)
Instruction will focus on basic strokes and techniques. Rules, strategy and play will be integrated as students' skills develop.

PE 1017. BEGINNING SWIMMING.
Cat. I (1/12 unit)
For the non-swimmer. Students will receive instruction in basic survival skills and the primary techniques to learn to swim safely.

PE 1018. CO-ED VOLLEYBALL.
Cat. I (1/12 unit)
Introduction to basic rules and individual/team skill development with practical application through game competition.

PE 1019. SOCCER.
Cat. I
Introduction to basic rules and individual/team skill development with practical application through game competition.

PE 1054. PLYOMETRICS.
Cat. I (1/12 unit)
This course will teach the use of body weight to develop personal strength and conditioning.

PE 1055. PHYSICAL CONDITIONING.
Cat. I (1/12 unit)
This course will teach basic strength training principles and techniques. Students will develop and implement an individualized conditioning program.

PE 1059. WEIGHT TRAINING FOR BEGINNERS.
Cat. I (1/12 unit)
The goal of course is to provide students with the knowledge and skills in basic weight training. This course is designed to educate students about the proper use of weight training equipment and how to create their own weight training exercise program. The basic essentials for starting a weight training routine.

PE 1070. LEISURE EDUCATION: REDEFINING SOCIAL NORMS.
Cat. I (1/12 unit)
Introductory course designed to explore various leisure education alternatives.

PE 1077. SWIMMING FOR FITNESS.
Cat. I (1/12 unit)
For the intermediate to advanced swimmer. This class is geared toward swimming for fitness purposes. Workouts will be administered each class period with students developing the knowledge to create workouts for themselves.

PE 1078. AQUATIC CONDITIONING.
Cat. I
This course will teach aquatic conditioning (aerobics, walking, strength and interval training) with the goal for students to develop and implement an individualized aquatic conditioning program for themselves. For the intermediate and advanced swimmer. All classes will be conducted on-campus through the use of the pool located in the Sports and Recreation Center.

PE 1080. AQUATIC GAMES.
Cat. I (1/12 unit)
Students will develop an understanding and appreciation of a variety of aquatic games through skill development and game play.

PE 1099. HEALTHY ALTERNATIVE PHYSICAL EDUCATION COURSES.
Cat. I (1/12 unit)
In each term, specific PE courses are offered to provide a variety of wellness, dance and healthy alternatives to traditional PE sport-based classes. The specific courses are subject to change on a yearly basis in order to provide flexibility in the PE offerings based upon the latest trends in wellness and dance. The focus of these classes is more on individual fitness, wellness and education, with instruction provided to all students in the classes.

CLUB SPORTS PROGRAM (PE 1200-series)

PE 1201	Club Sport - Alpine Ski Team
PE 1202	Club Sport - Badminton
PE 1203	Club Sport - Ballroom Dancing
PE 1204	Club Sport - Dance Team
PE 1205	Club Sport - Fencing Team
PE 1206	Club Sport - Ice Hockey Team
PE 1207	Club Sport - Karate
PE 1208	Club Sport - Men's Rugby Team
PE 1209	Club Sport - Women's Rugby Team
PE 1210	Club Sport - Men's Ultimate Frisbee Team
PE 1211	Club Sport - Women's Ultimate Frisbee Team
PE 1212	Club Sport - Men's Lacrosse Team
PE 1213	Club Sport - Women's Lacrosse Team
PE 1214	Club Sport - Men's Volleyball Team
PE 1215	Club Sport - Outing: Bouldering
PE 1216	Club Sport - Pep Band
PE 1217	Club Sport - Sailing
PE 1218	Club Sport - Social Dance
PE 1219	Club Sport - SOMA: Capoeira
PE 1220	Club Sport - SMAS: Boffer Games
PE 1221	Club Sport - Running

VARSITY ATHLETICS PROGRAM (PE 2000-series)

PE 2001	Varsity Football Team
PE 2002	Varsity Men's Soccer Team
PE 2003	Varsity Women's Soccer Team
PE 2004	Varsity Field Hockey Team
PE 2005	Varsity Women's Volleyball Team
PE 2006	Varsity Men's & Women' Cross Country Team
PE 2007	Varsity Wrestling Team
PE 2008	Varsity Men's Basketball Team
PE 2009	Varsity Women's Basketball Team
PE 2010	Varsity Men's & Women's Swim Team
PE 2011	Varsity Men's & Women's Indoor Track Team
PE 2012	Varsity Baseball Team
PE 2013	Varsity Softball Team
PE 2014	Varsity Men's & Women's Outdoor Track Team
PE 2015	Varsity Men's Crew Team
PE 2016	Varsity Women's Crew Team

PHYSICS

The second digit in physics course numbers is coded as follows.

1 — General physics
2 — Theoretical mechanics, statistical physics, kinetic theory, etc.
3 — Electricity and magnetism, electromagnetic theory
4 — Quantum mechanics
5 — Particular topics
6 — Laboratory

INTRODUCTORY PHYSICS SEQUENCE

There are four course topics in the introductory physics sequence. The four topics are Classical Mechanics (PH 1110/PH 1111), Electricity and Magnetism (PH 1120/PH 1121), Modern Physics (PH 1130), and Oscillations and Waves (PH 1140). Each course includes a laboratory component.

Students should take either PH 1110 or PH 1111, but not both; similarly, either PH 1120 or PH 1121, but not both. The primary difference between the PH 1110-PH 1120 option and PH 1111-PH 1121 is that the material in PH 1111- PH 1121 is treated somewhat more formally and rigorously than in PH 1110-PH 1120, thus presuming a better-than-average mathematics background. The recommended mathematics background for each course is indicated in the respective course description and should be considered carefully in each case.

Because the topics covered in the two mechanics and in the two electricity and magnetism courses are the same, it is possible to cross over from one sequence to the other. For example, PH 1120 could be taken after PH 1111, or, upon consulting with the course instructor, PH 1121 could be taken after successful completion of PH 1110. Finally, it should be noted that any combination of the first two introductory courses provides adequate preparation for both of the remaining courses in Modern Physics (PH 1130), and Oscillations and Waves (PH 1140).

The courses in classical mechanics and electricity and magnetism are regarded as essential preparation for many fundamental engineering courses as well as for further work in physics. PH 1130 gives a first introduction to modern physics and is designed to provide a context for the appreciation of present-day advances in physics and high-technology applications. PH 1140 deals in depth with oscillating systems, a topic area of fundamental importance in physics, and whose engineering applications span the range from electromagnetic oscillations to the mechanical vibrations of machinery and structures.

PH 1110. GENERAL PHYSICS—MECHANICS.
Cat. I
Introductory course in Newtonian mechanics.

Topics include: kinematics of motion, vectors, Newton's laws, friction, work-energy, impulse-momentum, for both translational and rotational motion.

Recommended background: concurrent study of MA 1021.

Students may not receive credit for both PH 1110 and PH 1111.

PH 1111. PRINCIPLES OF PHYSICS—MECHANICS.
Cat. I
An introductory course in Newtonian mechanics that stresses invariance principles and the associated conservation laws.

Topics include: kinematics of motion, vectors and their application to physical problems, dynamics of particles and rigid bodies, energy and momentum conservation, rotational motion.

Recommended background: concurrent study of MA 1023 (or higher). Students with limited prior college-level calculus preparation are advised to take PH 1110.

Students may not receive credit for both PH 1111 and PH 1110.

PH 1120. GENERAL PHYSICS—ELECTRICITY AND MAGNETISM.
Cat. I
An introduction to the theory of electricity and magnetism.

Topics include: Coulomb's law, electric and magnetic fields, capacitance, electrical current and resistance, and electromagnetic induction.

Recommended background: working knowledge of the material presented in PH 1110 or PH 1111 and concurrent study of MA 1022.

Students may not receive credit for both PH 1120 and PH 1121.

PH 1121. PRINCIPLES OF PHYSICS—ELECTRICITY AND MAGNETISM.
Cat. I
An introduction to electricity and magnetism, at a somewhat higher mathematical level than PH 1120.

Topics include: Coulomb's Law, electric fields and potentials, capacitance, electric current and resistance, magnetism, and electromagnetic induction.

Recommended background: working knowledge of material covered in PH 1111 and concurrent study of MA 1024 (or higher). Students concurrently taking MA 1022 or MA 1023 are advised to take PH 1120.

Students may not receive credit for both PH 1121 and PH 1120.

PH 1130. MODERN PHYSICS.
Cat. I
An introduction to the pivotal ideas and developments of twentieth-century physics.

Topics include: special relativity, photoelectric effect, X-rays, Compton scattering, blackbody radiation, DeBroglie waves, uncertainty principle, Bohr theory of the atom, atomic nuclei, radioactivity, and elementary particles.

Recommended background: familiarity with material covered in PH 1110 and PH 1120 (or PH 1111 and PH 1121) and completion of MA 1021 and MA 1022.

PH 1140. OSCILLATIONS, AND WAVES.
Cat. I
An introduction to oscillating systems and waves.

Topics include: free, clamped forced, and coupled oscillations of physical systems, traveling waves and wave packets, reflection, and interference phenomena.

Recommended background: working knowledge of the material covered in PH 1110 and PH 1120 (or PH 1111 and PH 1121) and completion of MA 1021, MA 1022 and MA 1023.

PH 2101. PRINCIPLES OF THERMODYNAMICS.
Cat. I
The course provides fundamental preparation for any specialized application of thermodynamics. The material covered includes a general description of large number systems, states, canonical state variables, state functions, response functions, and equations of state. Focus will be given to the physical meanings of free-energies, enthalpy, chemical potential, and entropy. Connections will be made to equilibrium states, reversible versus irreversible processes, phases and phase transformation, as well as the arrow of time as applied across disciplines.

Recommended background: introductory mechanics and multi-variable calculus

PH 2201. INTERMEDIATE MECHANICS I.
Cat. I
This course emphasizes a systematic approach to the mathematical formulation of mechanics problems and to the physical interpretation of the mathematical solutions.

Topics covered include: Newton's laws of motion, kinematics and dynamics of a single particle, vector analysis, motion of particles, rigid body rotation about an axis.

Recommended background: PH 1110, PH 1120, PH 1130, PH 1140, MA 1021, MA 1022, MA 1023, MA 1024 and concurrent registration in or completion of MA 2051.

PH 2202. INTERMEDIATE MECHANICS II.
Cat. I
This course is a continuation of the treatment of mechanics started in PH 2201. Topics covered include: rigid-body dynamics, rotating coordinate systems, Newton's law of gravitation, central-force problem, driven harmonic oscillator, an introduction to generalized coordinates, and the Lagrangian and Hamiltonian formulation of mechanics.

PH 2301. ELECTROMAGNETIC FIELDS.
Cat. I
Introduction to the theory and application of electromagnetic fields, appropriate as a basis for further study in electromagnetism, optics, and solid-state physics.
Topics: electric field produced by charge distributions, electrostatic potential, electrostatic energy, magnetic force and field produced by currents and by magnetic dipoles, introduction to Maxwell's equations and electromagnetic waves.
Recommended background: introductory electricity and magnetism, vector algebra, integral theorems of vector calculus as covered in MA 2251.

PH 2501. PHOTONICS.
Cat. II
An introduction to the use of optics for transmission and processing of information. The emphasis is on understanding principles underlying practical photonic devices. Topics include lasers, light emitting diodes, optical fiber communications, fiber lasers and fiber amplifiers, planar optical waveguides, light modulators and photodetectors. Recommended background is PH 1110, PH 1120, PH 1130 and PH 1140 (or their equivalents).
This course will be offered in 2020-21, and in alternating years thereafter.

PH 2502. LASERS.
Cat. II
An introduction to the physical principles underlying lasers and their applications. Topics will include the coherent nature of laser light, optical cavities, beam optics, atomic radiation, conditions for laser oscillation, optical amplifiers (including fiber amplifiers), pulsed lasers (Q switching and mode locking), laser excitation (optical and electrical), and selected laser applications. Recommended background is PH 1110, PH 1120, PH 1130 and PH 1140 (or their equivalents).
This course will be offered in 2019-20, and in alternating years thereafter.

PH 2510. ATOMIC FORCE MICROSCOPY.
Cat. II
Atomic force microscopes (AFMs) are instruments that allow three-dimensional imaging of surfaces with nanometer resolution and are important enabling tools for nanoscience and technology. The student who successfully completes this course will understand the functional principles of AFMs, be able to run one, and interpret the data that are collected.
Recommended background: PH 1110 and 1120. Suggested background: PH 1130 and PH 1140.
This course will be offered in 2019-20, and in alternating years thereafter.
Some sections of this course may be offered as Writing Intensive (WI).

PH 2520. INTRODUCTION TO ASTROPHYSICS.
Cat. II
A selective study of components of the universe (the solar system, stars, nebulae, galaxies) and of cosmology, based on astronomical observations analyzed and interpreted through the application of physical principles, and organized with the central purpose of presenting the latest understanding of the nature and evolution of the universe. Some topics to be covered include the Big Bang & Inflation; Stellar Behavior & Evolution; White Dwarfs, Neutron Stars, & Supernovae; Black Holes; Dark Matter & Dark Energy.
Recommended background is PH 1110 (or PH 1111), PH 1120 (or PH 1121), and especially PH 1130.
Suggested background: PH 1140.
This course will be offered in 2019-20, and in alternating years thereafter.

PH 2540. SOLAR SYSTEMS.
Cat. II
This course covers physics of the solar system and exo-planetary systems. Topics introduced will include the sun, moons and planets; the interplanetary space environment; gravitational interplay, planet atmospheres, surfaces and interiors; interplanetary travel, exploration and habitation; challenges of terraforming, comparison of planetary environments to Earth's biosphere; and the conditions required to support life.
Recommended background: a working knowledge of mechanics (PH 1110 or 1111), electrodynamics (PH 1120 or 1121), modern physics (PH 1130), and differential and integral calculus (MA 1021 and MA 1022).
This course will be offered in 2020-21, and in alternating years thereafter.

PH/AE 2550. ATMOSPHERIC AND SPACE ENVIRONMENTS.
Cat. I
This course introduces the ambient atmospheric and space environments encountered by aerospace vehicles. Topics include: the sun and solar activity; the solar wind; planetary magnetospheres; planetary atmospheres; radiation environments; galactic cosmic rays; meteoroids; and space debris.
Recommended background: mechanics (PH 1110/1111 or equivalent), electromagnetism (PH 1120/1121 or equivalent), and ordinary differential equations (MA 2051 or equivalent).

PH 2601. PHOTONICS LABORATORY.
Cat. II
This course provides an experimental approach to concepts covered in Photonics (PH 2501), Lasers (PH 2502), and Optics (PH 3504). Through a series of individually tailored experiments, students will reinforce their knowledge in one or more of these areas, while at the same time gaining exposure to modern photonics laboratory equipment. Experiments available include properties of optical fibers, optical fiber diagnostics, optical communications systems, properties of photodetectors, mode structure and threshold behavior of lasers, coherence properties of laser light, characterization of fiber amplifiers, diffraction of light, polarization of light, interferometry.
Recommended background: PH 1110/1111, PH 1120/1121. PH 1130, PH 1140, and one or more of the courses PH 2501, PH 2502, or PH 3504. No prior laboratory background is expected.
This course will be offered in 2020-21, and in alternating years thereafter.

PH 2651. INTERMEDIATE PHYSICS LABORATORY.
Cat. I
This course offers experience in experimentation and observation for students of the sciences and others. In a series of subject units, students learn or review the physical principles underlying the phenomena to be observed and the basis for the measurement techniques employed. Principles and uses of laboratory instruments including the cathode-ray oscilloscope, meters for frequency, time, electrical and other quantities are stressed. In addition to systematic measurement procedures and data recording, strong emphasis is placed on processing of the data, preparation and interpretation of graphical presentations, and analysis of precision and accuracy, including determination and interpretation of best value, measures of error and uncertainty, linear best fit to data, and identification of systematic and random errors. Preparation of high-quality experiment reports is also emphasized. Representative experiment subjects are: mechanical motions and vibrations; free and driven electrical oscillations; electric fields and potential; magnetic materials and fields; electron beam dynamics; optics; diffraction-grating spectroscopy; radioactive decay and nuclear energy measurements.
Recommended background: the Introductory Physics course sequence or equivalent. No prior laboratory background beyond that experience is required.
Students who have received credit for PH 2600 or PH 3600 may not receive credit for PH 2651.

PH 3206. STATISTICAL PHYSICS.
Cat. I
An introduction to the basic principles of thermodynamics and statistical physics.
Topics covered include: basic ideas of probability theory, statistical description of systems of particles, thermodynamic laws, entropy, microcanonical and canonical ensembles, ideal and real gases, ensembles of weakly interacting spin 1/2 systems.
Recommended background: knowledge of quantum mechanics and thermodynamics at the level of ES 3001.

PH 3301. ELECTROMAGNETIC THEORY.
Cat. I
A continuation of PH 2301, this course deals with more advanced subjects in electromagnetism, as well as study of basic subjects with a more advanced level of mathematical analysis. Fundamentals of electric and magnetic fields, dielectric and magnetic properties of matter, quasi-static time-dependent phenomena, and generation and propagation of electromagnetic waves are investigated from the point of view of the classical Maxwell's equations.

PH 3401. QUANTUM MECHANICS I.
Cat. I
This course includes a study of the basic postulates of quantum mechanics, its mathematical language and applications to one-dimensional problems. The course is recommended for physics majors and other students whose future work will involve the application of quantum mechanics.
Topics include wave packets, the uncertainty principle, introduction to operator algebra, application of the Schroedinger equation to the simple harmonic oscillator, barrier penetration and potential wells.

Recommended background: Junior standing, MA 4451, and completion of the introductory physics sequence, including the introduction to the 20th century physics.
Suggested background: knowledge (or concurrent study) of linear algebra, Fourier series, and Fourier transforms.

PH 3402. QUANTUM MECHANICS II.
Cat. I
This course represents a continuation of PH 3401 and includes a study of three-dimensional systems and the application of quantum mechanics in selected fields.
Topics include: the hydrogen atom, angular momentum, spin, perturbation theory and examples of the application of quantum mechanics in fields such as atomic and molecular physics, solid state physics, optics, and nuclear physics.
Recommended background: PH 3401.

PH 3501. RELATIVITY.
Cat. II
This course is designed to help the student acquire an understanding of the formalism and concepts of relativity as well as its application to physical problems.
Topics include the Lorentz transformation, 4-vectors and tensors, covariance of the equations of physics, transformation of electromagnetic fields, particle kinematics and dynamics.
Recommended background: knowledge of mechanics and electrodynamics at the intermediate level.
This course will be offered in 2020-21, and in alternating years thereafter.

PH 3502. SOLID STATE PHYSICS.
Cat. II
An introduction to solid state physics.
Topics include: crystallography, lattice vibrations, electron band structure, metals, semiconductors, dielectric and magnetic properties.
Recommended background: prior knowledge of quantum mechanics at an intermediate level.
Suggested background: knowledge of statistical physics is helpful.
This course will be offered in 2020-21, and in alternating years thereafter.

PH 3503. NUCLEAR PHYSICS.
Cat. II
This course is intended to acquaint the student with the measurable properties of nuclei and the principles necessary to perform these measurements. The major part of the course will be an introduction to the theory of nuclei.
The principal topics will include binding energy, nuclear models and nuclear reactions. The deuteron will be discussed in detail and the nuclear shell model will be treated as well as the nuclear optical model.
Recommended background: some knowledge of the phenomena of modern physics at the level of an introductory physics course and knowledge of intermediate level quantum mechanics.
This course will be offered in 2019-20, and in alternating years thereafter.

PH 3504. OPTICS.
Cat. II
This course provides an introduction to classical physical optics, in particular interference, diffraction and polarization, and to the elementary theory of lenses. The theory covered will be applied in the analysis of one or more modern optical instruments.
Recommended background: knowledge of introductory electricity and magnetism and of differential equations.
Suggested background: PH 2301.
This course will be offered in 2019-20, and in alternating years thereafter.

PH 4201. ADVANCED CLASSICAL MECHANICS.
Cat. I
A review of the basic principles and introduction to advanced methods of mechanics, emphasizing the relationship between dynamical symmetries and conserved quantities, as well as classical mechanics as a background to quantum mechanics.
Topics include: Lagrangian mechanics and the variational principle, central force motion, theory of small oscillations, Hamiltonian mechanics, canonical transformations, Hamilton-Jacobi Theory, rigid body motion, and continuous systems.
Recommended background: PH 2201 and PH 2202.
This is a 14-week course.

Graduate Physics Courses of Interest to Undergraduates

PH 511/PH 4201. CLASSICAL MECHANICS.

PH 514. QUANTUM MECHANICS I.

PH 515. QUANTUM MECHANICS II.

PH 522. THERMODYNAMICS AND STATISTICAL MECHANICS.

PH 533. ADVANCED ELECTROMAGNETIC THEORY.

NSE 510. INTRODUCTION TO NUCLEAR SCIENCE AND ENGINEERING.

NSE 520. APPLIED NUCLEAR PHYSICS

See Graduate Catalog for details.

ROBOTICS ENGINEERING

RBE 1001. INTRODUCTION TO ROBOTICS.
Cat. I
Multidisciplinary introduction to robotics, involving concepts from the fields of electrical engineering, mechanical engineering and computer science. Topics covered include sensor performance and integration, electric and pneumatic actuators, power transmission, materials and static force analysis, controls and programmable embedded computer systems, system integration and robotic applications. Laboratory sessions consist of hands-on exercises and team projects where students design and build mobile robots.
Undergraduate credit may not be earned for both this course and for ES 2201.
Recommended background: mechanics (PH 1110/PH 1111).

RBE 2001. UNIFIED ROBOTICS I: ACTUATION.
Cat. I
First of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is the effective conversion of electrical power to mechanical power, and power transmission for purposes of locomotion, and of payload manipulation and delivery. Concepts of energy, power and kinematics will be applied. Concepts from statics such as force, moments and friction will be applied to determine power system requirements and structural requirements. Simple dynamics relating to inertia and the equations of motion of rigid bodies will be considered. Power control and modulation methods will be introduced through software control of existing embedded processors and power electronics. The necessary programming concepts and interaction with simulators and Integrated Development Environments will be introduced. Laboratory sessions consist of hands-on exercises and team projects where students design and build robots and related sub-systems.
Recommended background: ES 2201/RBE 1001, ES 2501 (can be taken concurrently), ECE 2029 and PH 1120 or PH 1121.

RBE 2002. UNIFIED ROBOTICS II: SENSING.
Cat. I
Second of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is interaction with the environment through sensors, feedback and decision processes. Concepts of stress and strain as related to sensing of force, and principles of operation and interface methods for electronic transducers of strain, light, proximity and angle will be presented. Basic feedback mechanisms for mechanical systems will be implemented via electronic circuits and software mechanisms. The necessary software concepts will be introduced for modular design and implementation of decision algorithms and finite state machines. Laboratory sessions consist of hands-on exercises and team projects where students design and build robots and related sub-systems.
Recommended background: RBE 2001, CS 1101 or CS 1102

RBE 3001. UNIFIED ROBOTICS III: MANIPULATION.
Cat. I
Third of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is actuator design, embedded computing and complex response processes. Concepts of dynamic response as relates to vibration and motion planning will be presented. The principles of operation and interface methods various actuators will be discussed, including pneumatic, magnetic, piezoelectric, linear, stepper, etc. Complex feedback mechanisms will be implemented using software executing in an embedded system. The necessary concepts for real-time processor programming, re-entrant code and interrupt signaling will be introduced. Laboratory sessions will culminate in the construction of a multi-module robotic system that exemplifies methods introduced during this course.
Recommended background: RBE 2002, ECE 2049, CS 2102 or CS 2103, MA 2051, and MA 2071.

RBE 3002. UNIFIED ROBOTICS IV: NAVIGATION.
Cat. I
Fourth of a four-course sequence introducing foundational theory and practice of robotics engineering from the fields of computer science, electrical engineering and mechanical engineering. The focus of this course is navigation, position estimation and communications. Concepts of dead reckoning, landmark updates, inertial sensors, and radio location will be explored. Control systems as applied to navigation will be presented. Communication, remote control and remote sensing for mobile robots and tele-robotic systems will be introduced. Wireless communications including wireless networks and typical local and wide area networking protocols will be discussed. Considerations will be discussed regarding operation in difficult environments such as underwater, aerospace, hazardous, etc. Laboratory sessions will be directed towards the solution of an open-ended problem over the course of the entire term.
Recommended background: RBE 3001, ES 3011, MA 2621, or MA 2631.

RBE 3100. SOCIAL IMPLICATIONS OF ROBOTICS.
Cat.I
This course introduces students to the social, moral, ethical, legal, and current or future philosophical issues within the context of robotic systems and related emerging technology. Students will be expected to contribute to classroom presentations, discussions and debates, and to complete a number of significant writing assignments. This course is recommended for juniors and seniors.
Recommended background: A general knowledge of robots and robotic systems.
Students may not receive credit for both RBE 3100 and RBE 310X.

RBE/ME 4322. MODELING AND ANALYSIS OF MECHATRONIC SYSTEMS.
Cat. I
This course introduces students to the modeling and analysis of mechatronic systems. Creation of dynamic models and analysis of model response using the bond graph modeling language are emphasized. Lecture topics include energy storage and dissipation elements, transducers, transformers, formulation of equations for dynamic systems, time response of linear systems, and system control through open and closed feedback loops. Computers are used extensively for system modeling, analysis, and control. Hands-on projects will include the reverse engineering and modeling of various physical systems. Physical models may sometimes also be built and tested.
Recommended background: mathematics (MA 2051, MA 2071), fluids (ES 3004), thermodynamics (ES 3001), mechanics (ES 2501, ES 2503)

RBE/ME 4815. INDUSTRIAL ROBOTICS.
Cat. I
This course introduces students to robotics within manufacturing systems. Topics include: classification of robots, robot kinematics, motion generation and transmission, end effectors, motion accuracy, sensors, safety systems, robot control and automation. This course is a combination of lecture, laboratory and project work, and utilizes industrial robots. Through the laboratory work, students will become familiar with robotic programming (using a robotic programming language RAPID) and the robotic teaching mode. The experimental component of the laboratory exercise measures the motion and positioning capabilities of robots as a function of several robotic variables and levels, and it includes the use of experimental design techniques.
Recommended background: manufacturing (ME 1800), kinematics (ME 3310), control (ES 3011), and computer programming.

SOCIAL SCIENCE AND POLICY STUDIES

DEV	Development
ECON	Economics
ENV	Environmental Studies
GOV	Political Science, Government and Law
PSY	Psychology
SD	System Dynamics
SOC	Sociology
SS	General Social Science
STS	Society/Technology Studies

DEVELOPMENT (DEV)

DEV 1200. INTERNATIONAL DEVELOPMENT AND SOCIETY.
Cat. I
What is development? How has international development been understood and what has been done about it? How do development scholars explain why some countries are rich while others are poor? How can students understand and incorporate development studies in the contexts of their own global engagements? This course addresses these questions by looking at theories, ideologies, and processes that have influenced and embodied development thinking and practice over the past five decades. We will examine the role of colonization, modernization, dependency, globalization, democratization, industrialization, and urbanization in processes of development in countries across the globe. The course encourages students to think critically about what development is, about how it is carried out and, most importantly of all, about what it can achieve. DEV 1200 provides excellent preparation for international projects and careers.
Recommended background: None.

DEV 2200. CASE STUDIES IN INTERNATIONAL DEVELOPMENT POLICY AND ENGINEERING.
Cat. II
The engineers and scientists of tomorrow have a crucial role to play in discovering and implementing solutions to daunting international challenges related to food, water, energy, sanitation and infrastructure. The urgency of such challenges grows alongside and increasingly globalized workplace, where a growing number of graduates find themselves working outside the US, and invited to engage cultures, worldviews, value systems and physical environments that are very unlike their own. This course prepares students with 'global competency', to enable them to more effectively and ethically tackle problems in the context of starkly different socioeconomic, political, social and physical realities. Students will develop the knowledge, skills and understanding required to consider, accommodate and effectively integrate contextual difference into engineering practice by exploring the complexity of project design, the potential for unintended consequences, and how technologies are transformed in different contexts. This course will prepare students for a broad range of international IQP and MQPs.
Recommended background: None.
This course will be offered in 2020-21, and in alternating years thereafter.

DEV 4400. SCIENCE, ENGINEERING AND DESIGN IN INTERNATIONAL DEVELOPMENT.
Cat. II
This course provides students with a set of skills that will allow them to address complex problems and design challenges in development engineering. Students will learn to participate in and lead innovation and creativity in collaborative settings. This course includes design projects and case studies, many related to projects at WPI. Student teams will work with preliminary data to define the problem. They will then collect and analyze interview and survey data to learn about user needs. Students will explore how to understand end-user needs. Students will use a variety of tools to analyze their data, ideate potential solutions, and prototype. The teams will use their projects to develop plans for rapid improvement, scaling, continuous improvement and a rigorous impact evaluation.
Recommended background: None.
This course will be offered in 2021-22, and in alternating years thereafter.

ECONOMICS (ECON)

ECON 1110. INTRODUCTORY MICROECONOMICS.
Cat. I
The course focuses upon the implications of reliance upon markets for the allocation of resources in a society, at the household, firm, and community level. Outcomes of current market systems are examined in terms of the efficient use of natural and other economic resources, as well as their impact upon the environment, fairness, and social welfare. of special interest in these analyses is the role of prices in the determination of what commodities are produced, their means of production, and distribution among households. In cases where current market outcomes have features subject to widespread criticism, such as the presence of excessive pollution, risk, discrimination, and poverty, the analysis is extended to suggest economic solutions. There are no prerequisites for the course.

ECON 1120. INTRODUCTORY MACROECONOMICS.
Cat. I
This course is designed to acquaint students with the ways in which macroeconomic variables such as national income, employment and the general level of prices are determined in an economic system. It also includes a study of how the techniques of monetary policy and fiscal policy attempt to achieve stability in the general price level and growth in national income and employment. The problems of achieving these national goals (simultaneously) are also analyzed. The course stresses economic issues in public policy and international trade.

ECON 2110. INTERMEDIATE MICROECONOMICS.
Cat. II
The topics addressed in this course are similar to those covered in ECON 1110 (Introductory Microeconomics) but the treatment proceeds in a more rigorous and theoretical fashion to provide a firm platform for students majoring in Economics or Business, or those having a strong interest in economics. Mathematics at a level comparable to that taught in MA 1021-MA 1024 is frequently applied to lend precision to the analysis. The course rigorously develops the microeconomic foundations of the theory of the firm, the theory of the consumer, the theory of markets, and the conditions required for efficiency in economic systems.
Recommended background: ECON 1110.
This course will be offered in 2019-20, and in alternating years thereafter.

ECON 2117. ENVIRONMENTAL ECONOMICS.
Cat. II
This course investigates the effect of human activity upon the environment as well as the effect of the environment on human well beingwell-being. It pays special attention to the impact of production and consumption of material goods upon the quantity and quality of environmental goods. The analysis focuses on the challenges presented in mixed economics where markets are combined with government intervention to manage pollution and scarcity. The course reviews efforts to measure the costs and benefits of improving environmental conditions and evaluates current and potential policies in terms of the costs of the environmental improvements they may yield. Attention is also paid to the special difficulties which arise when the impacts of pollution spill across traditional political boundaries. Recommended background: ECON 1110.
This course will be offered in 2020-21, and in alternating years thereafter.

ECON 2120. INTERMEDIATE MACROECONOMICS.
Cat. II
This course is an advanced treatment of macroeconomic theory well suited for students majoring in Economics or Business, or others with a strong interest in economics. The topics addressed in ECON 2120 are similar to those covered in ECON 1120, however the presentation of the material will proceed in a more rigorous and theoretical fashion.
Recommended background: ECON 1110.
This course will be offered in 2020-21, and in alternating years thereafter.

ECON 2125. DEVELOPMENT ECONOMICS.
Cat. II
This course is a general introduction to the field of development economics. The focus is on ways in which a developing country can increase its productive capacity, both agricultural and industrial, in order to achieve sustained economic growth. The course proceeds by first examining how economic growth and economic development are measured and how the various nations of the world compare according to well-known social and economic indicators. Theories of economic growth and theories of economic development are then examined, as are the various social and cultural structures that are thought to influence economic progress. The inputs to economic growth and development (land, labor, capital, entrepreneurial ability, education, technical change), and the possible distributions of income and levels of employment that result from their use, is considered next. Domestic economic problems and policies such as development planning, the choice of sectorial policies, the choice of monetary and fiscal policies, rapid population growth, and urbanization and urban economic development are then examined. The course concludes with a consideration of international problems and policies such as import substitution and export promotion, foreign debt, foreign investment, and the role of international firms. In conjunction with a traditional presentation of the above topics, the course curriculum will include the use of computer simulation models and games. These materials have been formulated with a simulation technique, system dynamics, that has its origins in control engineering and the theory of servomechanisms. As a result, students will find them complementary to their work in engineering and science. In addition, the various development theories and simulation and gaming results will be related, where possible, to specific developing nations where WPI has on-going project activities (e.g., Costa Rica and Thailand). This course is recommended for those students wishing to do an IQP or MQP in a developing nation.
Recommended background: ECON 1120.
This course will be offered in 2019-20, and in alternating years thereafter.

ECON 2126. PUBLIC ECONOMICS.
Cat. II
This course examines the economics of government expenditure and taxation. On the expenditure side, the course will review why governments often choose to be involved in the provision of healthcare, education, national defense, a clean environment, and infrastructure such as roads and bridges. It will also delve into the rationale behind programs such as social security. Regarding taxation, the course will cover income, consumption, and corporate taxes, including the use of corrective taxes to address market failures due to externalities. Within each topic, the relevant economic theories will be presented, and then students will practice applying the theories to real-world examples. As such, there will be plenty of opportunity to discuss policy implications and debate proposed policy changes.
Recommended background: Some introductory economics, such as Introductory Micro- or Macroeconomics (ECON 1110 or ECON 1120; or equivalent).
Students who completed ECON 212X: Public Economics cannot receive credit for ECON 2126: Public Economics.

ECON 2130. ECONOMETRIC MODELING.
Cat. II
Econometrics helps governments and businesses make more informed economic decisions. This course introduces the application of statistics and economic theory to formulating, estimating, and testing models about relationships among key variables. Topics include basic data analysis, regression analysis (including estimation, inference, assumptions, violations of assumptions, corrections for violations, dummy variables), and forecasting. Students will have the opportunity to use real-world socioeconomic data to test and interpret economic theories using econometric software. Successful students should also be able to formulate, estimate, and interpret their own testable relationships in other projects or fields of study.
Recommended Background: Some previous exposure to Economics, such as ECON 1110 and/or ECON 1120.
Students may not get credit both for ECON 1130 and ECON 2130

ECON 2135. INFORMATION ECONOMICS AND POLICY.
Cat. II
This course provides an introduction to the economics, business strategies, and regulatory and legal aspects of telecommunication markets. The analysis of complex interactions between technology, Federal and state government policies, copyright legislation, and forces driving supply and demand is performed using Economic and Industrial Organization theories combined with computer simulation techniques. Topics include, among others: the economics of telephony services, cable TV, satellite communication, spectrum auctions, WLAN, and peer-to-peer file sharing. Special attention will be paid to the analysis of the latest regulatory and legal developments in the telecommunications industry.
Recommended background: ECON 1110 or ECON 2110.
This course will be offered in 2020-21, and in alternating years thereafter.

ECON 2145. BEHAVIORAL ECONOMICS.
Cat. I
Behavioral economics incorporates insights from psychology and sociology into economic models of decision-making. While traditional economic theory typically assumes individuals are self-interested and have an infinite ability to analyze and understand their decision-making environment, behavioral economics relaxes these assumptions in light of evidence from the field of experimental economics. Topics in the course include social preferences, mental accounting, decision-making under uncertainty and intertemporal choice. Additional topics may include the economics of social identity, preference formation and learning. Decision-making processes will be examined using simple economic experiments conducted in class.
Recommended background: ECON 1110.

ECON 2155. EXPERIMENTAL ECONOMICS.
Cat. II
Experimental economics is a set of methods for testing hypotheses about behavior. Traditional economic analysis using naturally occurring data is often confounded by the complexities of the real world. Economic experiments, on the other hand, give researchers the control required for isolating behaviors of interest. As such, economic experiments can be useful tools for testing existing theories and establishing empirical regularities assisting in the development of new theories. In this course, we cover the basic principles of experimental design. We also study a number of classic experiments, on topics ranging from the efficiency of markets to decision-making under uncertainty and behavioral game theory. Students will participate in mock experiments and will begin putting their new skills into practice by designing their own experiments, which may serve as the basis for IQPs/MQPs. If time permits, we will discuss some of the basic methods for analyzing experimental data, which presents challenges somewhat different from naturally occurring data due to small sample sizes.
Recommended Background: ECON 1110
This course will be offered in 2019-20, and in alternating years thereafter.

ECON/ETR 2910. ECONOMICS AND ENTREPRENEURSHIP.
Cat. I
This course is designed to provide an introduction to economics, an introduction to entrepreneurship, and an understanding of the linkages between economics and entrepreneurship. Students will apply these concepts to the assessment of opportunities that might arise from participation in WPI projects. Students will engage in exploring how economics and entrepreneurship can inform opportunity assessment within an ambiguous and uncertain context. These decisions are always made with incomplete information and there is typically no single correct answer but rather multiple possible answers -- each with pluses and minuses.
Recommended background: None
Students may not earn credits for both ECON 2910/ETR 2910 and ECON 291X/ETR 291X

ENVIRONMENTAL AND SUSTAINABILITY STUDIES (ENV)

ENV 1100. INTRODUCTION TO ENVIRONMENTAL STUDIES.
Cat. I
The study of environmental problems and their solutions requires an interdisciplinary approach. This course will examine current environmental issues from the intersection of several key disciplines including: environmental philosophy and history, environmental policy, and science. The course will develop these different approaches for analyzing environmental problems, explore the tensions between them, and present a framework for integrating them. Topics such as environmental justice, developing nations, globalization, and climate change policy will be explored.

ENV 1500. INTRODUCTION TO GEOGRAPHICAL INFORMATION SYSTEMS.
Cat. II
This course introduces Geographic Information Systems (GIS) as a powerful mapping and analytical tool. Topics include GIS data structure, map projections, and fundamental GIS techniques for spatial analysis. Laboratory exercises concentrate on applying concepts presented in lectures and will focus on developing skills using ArcGIS. These exercises include examples of GIS applications in environmental modeling, socio-demographic change and site suitability analyses. Although the course is computer-intensive, no programming background is required.
This course will be offered in 2019-20, and in alternating years thereafter.
Note: Students may not receive credit for both ENV 150X and ENV 1500.

ENV 2201. PLANNING FOR SUSTAINABLE COMMUNITIES.
Cat. II
Sustainability planning seeks to anticipate and balance environmental, social, and economic impacts of human actions. This course presents an overview of how various perspectives can contribute to frameworks for environmental land use planning and management. Students are encouraged to think critically about problems land and natural resource use pose to society. Technical principles and analysis of sustainability planning are introduced and applied to challenges that communities currently face such as food, fiber and energy production, environmental conservation, hazard mitigation and resilience, water security, economic development, and waste management. Techniques to engage a diverse set of stakeholders in a collaborative planning process are examined along with the role of technology.
This course will be offered in 2019-20, and in alternating years thereafter.

ENV 2310. ENVIRONMENTAL GOVERNANCE AND INNOVATION.
Cat. II
With global attention dominated by environmental catastrophe and despair, we will spotlight new work that has brought together scientists, environmentalists, engineers, and artists to tackle the most serious problems facing communities. We will explore the political ecology implications of control over essential resources and the positive consequences of rethinking and democratizing basic social needs for a more sustainable future. Recent exciting case studies will feature examples of simple solutions that inspire elegant, transferrable, and inexpensive applications of technological design. We will examine the role and obligation that scientists have to collaborate with interdisciplinary and public policy efforts that benefit people with sustainable approaches to architecture, food, energy, transportation, and infrastructure.
Recommended background: introductory environmental studies course.
Students may not receive credit for both ENV 230X and ENV 2310.
This course will be offered in 2019-20, and in alternating years thereafter.

ENV 2400. ENVIRONMENTAL PROBLEMS AND HUMAN BEHAVIOR.
Cat. II
This course examines how people think about and behave toward the environment. Environmental problems can ultimately be attributed to the environmental decisions and actions of human beings. These behaviors can in turn be understood as resulting from the nature and limitations of the human mind and the social context in which behavior takes place. Knowledge of the root causes of environmentally harmful behavior is essential for designing effective solutions to environmental problems. The goals of the course are (1) to provide students with the basic social science knowledge needed to understand and evaluate the behavioral aspects of such important environmental problems as air and water pollution, global warming, ozone depletion, preserving biological diversity, and hazardous waste and (2) to help students identify and improve shortcomings in their knowledge and decisions related to the environment. Topics will include, but not be limited to: environmental problems as “tragedies of the commons”; public understanding of global warming and global climate modeling; folk biology; risk perception; intelligent criticism of environmental claims; making effective environmental choices; strategies for promoting pro-environmental behavior; and human ability to model and manage the global environmental future.
Recommended background: ENV 1100.
Suggested background: PSY 1400, PSY 1401, or PSY 1402.
Students may not receive credit for both PSY 2405 and ENV 2400.
This course will be offered in 2019-20, and in alternating years thereafter.

ENV 2600. ENVIRONMENTAL PROBLEMS IN THE DEVELOPING WORLD.
Cat. II
Environment and development are often seen as incompatible, in part because many poor people in the developing world depend directly on natural resources for their livelihoods. At the same time, poor people are often seen as responsible for causing environmental degradation because they lack the knowledge, skills and resources to manage the environment effectively. The vicious circle is completed as environmental degradation exacerbates poverty. However, optimists argue that poor people can and do contribute positively to environmental outcomes, that states and organizations can facilitate their efforts and that environmental interventions can coincide with development. This course will examine these different perspectives on environmental problems in the developing world through the insights and critiques of social science. Subjects

covered include sustainable development, population, environmental risks, gender, urbanization, environmental decision making, and non-governmental organizations (NGOs). The goals of this course are to think critically about the various links between environment and development and the role of governmental and non-governmental organizations in promoting sustainable development in the developing world.

Recommended Background: ENV 1100

This course will be offered in 2019-20, and in alternating years thereafter.

ENV 2700. SOCIAL MEDIA, SOCIAL MOVEMENTS, AND THE ENVIRONMENT.

Cat. II

Social media platforms are changing the world of social movements, giving rise to a new generation of social activism. Social media can enable local actors to link with others from across the globe to incite social and environmental change. Social media has enabled people to document and share injustices (e.g., violence; dumping of toxic waste) in places where freedom of the press is limited or non-existent, and it has enabled people across different social groups (race, class, etc.) to engage with one another on issues of shared concern. Social media has also allowed people to share resources (financial, expertise, and organizational) with other social actors across the globe, empowering communities in novel ways. This course introduces students to the phenomena of social and environmental movements, theories on why they succeed and fail, and how social media has changed the landscape of social mobilization. This course will draw on interdisciplinary readings, concepts, and case studies from the social sciences, with emphasis on geography, public policy, sociology, and media studies. Course work will include small group projects, analyses of current social movement cases, and a final project. The final project will consist of interviewing members of a current social movement (potentially using social media), evaluating whether particular social media applications have helped to enable social mobilization, and designing new or revised social media tools to further enhance social mobilization.

Recommended background: introductory environmental studies (ENV1100 or equivalent).

ENV 2900. THE GREEN ECONOMY AND MODELS FOR ALTERNATIVE FORMS OF DEVELOPMENT.

Cat. II

This course examines the limitations of traditional economic models and charts a new course for current policies and practices. To chart this path we draw upon and synthesize examples from existing alternative economies (e.g., different forms of dematerialization, hybrid organizations, solidary economy, sharing economy).The course critically examines current paradigms of greening and seeks to expand thinking that will encompass new, alternative, and socially just conceptions of economy and economic development. A particular emphasis is laid on the spatial implications of de-growth oriented activities which partly challenge existing models and research methods in economic geography.

Suggested background: Basic knowledge of economics and environmental governance.

This course will be offered in 2019-20, and in alternating years thereafter.

ENV 3100. ADVENTURES IN SUSTAINABLE URBANISM.

Cat. II

This course will take students on an adventure, both in the class and in the field. Students will examine the history of sustainable development, its antecedents, the factors that have influenced its evolution, and how the sustainable city came into existence. Students will be invited on a number of virtual field trips to sustainable cities from around the world. The goal will be to explore the underlying factors of sustainable urbanism, why it looks the way it does in different places, and how students can exercise their own agency in developing alternatives. Students will also develop their own field trips for publication on the course website.

Suggested background: introduction to environmental studies and a passion for urban exploration.

This course will be offered in 2019-20, and in alternating years thereafter.

ENV 4400. SENIOR SEMINAR IN ENVIRONMENTAL STUDIES.

Cat. I

This course is intended for Environmental Studies majors. The course is designed to integrate each student's educational experience (e.g., core environmental courses, environmental electives, and environmental projects) in a capstone seminar in Environmental Studies. Through seminar discussions and writing assignments students will critically reflect on what they learned in their previous courses and project experiences. In teams, students will prepare a final capstone paper and presentation that critically engages their educational experience in environmental studies and anticipates how their courses and experiences will translate into their future personal and professional environmental experiences.

Recommended background: ENV 1100, ENV 2200 or ENV 2400, completion or concurrent enrollment in IQP and MQP.

POLITICAL SCIENCE, GOVERNMENT AND LAW (GOV)

GOV 1301. U.S. GOVERNMENT.

Cat. I

This course is an introduction to the fundamental principles, institutions, and processes of the constitutional democracy of the United States. It examines the formal structure of the Federal system of government, including Congress, the presidency, the judiciary, and the various departments, agencies, and commissions which comprise the executive branch. Emphasis is placed on the relationships among Federal, state and local governments in the formulation and administration of domestic policies, and on the interactions among interest groups, elected officials and the public at large with administrators in the policy process. The various topics covered in the survey are linked by consideration of fiscal and budgetary issues, executive management, legislative oversight, administrative discretion, policy analysis and evaluation and democratic accountability.

GOV 1303. AMERICAN PUBLIC POLICY.

Cat. I

American Public Policy focuses on the outcomes or products of political institutions and political controversy. The course first addresses the dynamics of policy formations and stalemate, the identification of policy goals, success and failure in implementation, and techniques of policy analysis. Students are then encouraged to apply these concepts in the study of a specific policy area of their choosing, such as foreign, social, urban, energy or environmental policy. This course is an important first step for students wishing to complete IQPs in public policy research. Students are encouraged to complete GOV 1303 prior to enrolling in upper level policy courses such as GOV 2303, GOV 2304 or GOV 2311. There is no specific preparation for this course, but a basic understanding of American political institutions is assumed.

Some sections of this course may be offered as Writing Intensive (WI).

GOV 1310. LAW, COURTS, AND POLITICS.

Cat. II

This course is an introduction to law and the role courts play in society. The course examines the structure of judicial systems, the nature of civil and criminal law, police practice in the enforcement of criminal law, and the responsibilities of judges, attorneys and prosecutors. Additional topics for discussion include the interpretation of precedent and statue in a common law system and how judicial discretion enables interest groups to use courts for social change. The student is expected to complete the course with an understanding of how courts exercise and thereby control the power of the state. As such, courts function as political actors in a complex system of governance. It is recommended that students complete this course before enrolling in GOV 2310, Constitutional Law.

This course will be offered in 2019-20, and in alternating years thereafter.

GOV 1320. TOPICS IN INTERNATIONAL POLITICS.

Cat. II

GOV 1320 is a survey course designed to introduce students to the basic concepts of international relations: power and influence, nations and states, sovereignty and law. These concepts will be explored through the study of issues such as diplomacy and its uses, theories of collective security and conflict, and international order and development. The study of international organizations such as the UN, the European Union or the Organization of American States will also supplement the students' understanding of the basic concepts. The course may also include comparative political analysis of states or regions. It is designed to provide the basic background materials for students who wish to complete IQPs on topics that involve international relations or comparative political systems.

This course will be offered in 2019-20, and in alternating years thereafter.

GOV 2302. SCIENCE-TECHNOLOGY POLICY.
Cat. II
This course is an examination of the relationship between science-technology and government. It reviews the history of public policy for science and technology, theories and opinions about the proper role of government and several current issues on the national political agenda. Examples of these issues include genetic engineering, the environment and engineering education. It also examines the formation of science policy, the politics of science and technology, the science bureaucracy, enduring controversies such as public participation in scientific debates, the most effective means for supporting research, and the regulation of technology. Throughout the course we will pay particular attention to the fundamental theme: the tension between government demands for accountability and the scientific community's commitment to autonomy and self-regulation.
Recommended background: GOV 1301 or GOV 1303.
This course will be offered in 2019-20, and in alternating years thereafter.

GOV 2310. CONSTITUTIONAL LAW: FOUNDATIONS OF GOVERNMENT.
Cat. II
Constitutional Law is the study of Supreme Court decisions interpreting the U.S. Constitution. The Foundations course focuses on the powers of the Congress, the Presidency and the Judicial Branch, especially the Supreme Court's understanding of its own power. These cases reveal, in particular, the evolution of Federal power with the development of a national economy and the shifting balance of power among the three branches of government. Issues of state power in a federal system are also addressed. Lastly, these materials are examined in the context of the great debates regarding how judges interpret the Constitution. How are the words and intent of the Founders applicable to the legal and political conflicts of the twenty-first century?
This course will be offered in 2020-21, and in alternating years thereafter.

GOV 2311. ENVIRONMENTAL POLICY AND LAW.
Cat. I
This course deals with environmental law as it relates to people, pollution and land use in our society. A case method approach will be used to illustrate how the courts and legislators have dealt with these social-legal problems. The course is designed to have the student consider: 1) the legal framework within which environmental law operates; 2) the governmental institutions involved in the formulation, interpretation and application of environmental law; 3) the nature of the legal procedures and substantive principles currently being invoked to resolve environmental problems; 4) the types of hazards to the environment presently subject to legal constraints; 5) the impact that the mandates of environmental law have had, and will have, on personal liberties and property rights; 6) the role individuals and groups can play within the context of our legal system to protect and improve man's terrestrial habitat and the earth's atmosphere; and 7) some methods and sources for legal research that they may use on their own.
Recommended background: GOV 1303 or GOV 1310.

GOV 2312. INTERNATIONAL ENVIRONMENTAL POLICY.
Cat. II
Environmental issues present some of the major international problems and opportunities facing the world today. Worst-case scenarios envision irrevocable degradation of the earth's natural systems, but virtually every analysis sees the need for major change worldwide to cope with problems such as global warming, deforestation, ozone layer depletion, loss of biodiversity, and population growth, not to mention exponential increases in "conventional" pollutants in newly industrialized countries. The global environment issues represent a "second-generation" of environmental policy in which the focus of concern has moved from national regulations to international law and institutions. In addition, the environment has emerged as a major aspect of international trade, conditioning corporate investment and accounting for some $200 billion in sales of pollution control equipment in 1991. Exploration of the genesis and implications of these phenomena is the essence of the course. Topically, the material begins with the nature of global environmental problems, drawing on literature from large-scale global modeling as well as particular analyses of the problems mentioned above. Approximately half the course focuses on international laws and institutions, including multilateral treaties (e.g., the Montreal Protocol limiting CFC use, ocean dumping, biodiversity), international institutions (UNEP, the Rio Convention, the OECD) and private initiatives (international standards organizations, ICOLP (Industry Committee for Ozone Layer Protection), etc.) In addition, US policy toward global environmental issues will be compared with that in Japan, Europe and developing countries, from which it differs significantly. Students will design and undertake term projects that address particular issues in detail in an interdisciplinary manner.
Recommended background: GOV 1303.
This course will be offered in 2019-20, and in alternating years thereafter.

GOV 2313. INTELLECTUAL PROPERTY LAW.
Cat. II
Intellectual property includes ideas, and the works of inventors, authors, composers and other creative people. Patents, copyrights and trademarks establish legal rights in intellectual property. Alternatively, control over the use of an idea might be maintained by treating it as a trade secret. In these ways, the ideas of inventors and creators are protected and others are prohibited from appropriating the ideas and creative works of others. This course addresses the concept of intellectual property and the public policies that support the law of patent, copyright and trademark. Subjects include the process of obtaining patents, trademarks and copyrights; requirements of originality and, for patents, utility; infringement issues; and the problems posed by international trade and efforts to address them through the World Intellectual Property Organization.
Recommended background: GOV 1310 or GOV 2310.
This course will be offered in 2019-20, and in alternating years thereafter.

GOV/ID 2314. CYBERLAW AND POLICY.
Cat. II
Rapidly developing technologies for computing, information management and communications have been quickly adopted in schools, businesses and homes. The growth of the Internet and of e-commerce, in particular, have given rise to an entirely new set of legal issues as the courts, Congress and international bodies struggle to keep pace with changing technology. This course addresses the government's role in the development of these technologies and the legal issues that result including questions regarding privacy rights, speech and defamation, and the application of patent and copyright law. Policy questions such as surveillance of e-mail, regulation of content, mandates on the use of filters, and the responsibilities and liability of internet service providers are also discussed. Additional policies studied include attempts to control Internet content and enforce international judgments (resulting from e-commerce or cyber-crime) by foreign states and/or international organizations. Students are expected to integrate knowledge of technology with law, politics, economics and international affairs.
This course will be offered in 2020-21, and in alternating years thereafter.

GOV 2315. PRIVACY: LAWS, POLICY, TECHNOLOGY, AND HOW THEY FIT TOGETHER.
Cat. II
This course will begin by examining privacy in different societies, starting with Eastern Europe during the Cold War and moving west. We will look first at privacy and the threats to it from government, then privacy and the threats posed by business. We will consider various technologies (including online social networks, communication Devices, the Internet), and different regimes for protecting privacy (including law, regulation, and technology). The course is designed to develop critical thinking about the interactions between technology, policy, and the law as well as learning about the privacy tradeoffs one makes in using modern technologies.
Recommended background: GOV 1310 (Law, Courts, and Politics) or GOV 2310 (Constitutional Law).
This course will be offered in 2020-21, and in alternating years thereafter.

GOV 2319. GLOBAL ENVIRONMENTAL POLITICS.
Cat. II
It is apparent that environmental problems have outgrown national policy frameworks. Thus, institutions have emerged at the international and transnational levels to coordinate collective problem solving. But governance involves more than just the practicality of problem solving; it also involves uncertainty, controversy, power and politics. This course will examine the ways in which global environmental governance has been conceived: from establishing international institutions and agreements, to less tangible ways of interacting. We will examine themes such as scales of governance (from the United Nations to communities), policy networks, the role of NGOs, think tanks and special interests and the role of knowledge in global environmental debates. Students will then use this conceptual and theoretical basis to analyze major global environmental issues including: deforestation; biodiversity; endangered species; and climate change. The goals of this course are to gain an understanding of the main positions in global environmental debates; critically analyze these positions; and gain insight into the politics of global environmental policy and governance.
Recommended Background: GOV 1303 or GOV 1320
This course will be offered in 2019-20, and in alternating years thereafter.

GOV 2320. CONSTITUTIONAL LAW: CIVIL RIGHTS AND LIBERTIES.
Cat. II
Civil Rights and Liberties examines decisions of the Supreme Court which interpret the Bill of Rights and the Equal Protection Clause of the 14th Amendment. These court decisions elaborate the content and meaning of our rights to speak, publish, practice religion, and be free from state interference in those activities. Privacy rights broadly, the right to be free from unreasonable search and seizure, and due process rights for criminal suspects are also addressed. Finally, rights to be free from discrimination based on race, religion, ethnicity, gender and sexual orientation are examined in the context of equal protection law.

Students completing this course will receive credit toward the Minor in Law and Technology among the courses satisfying the requirement in "legal fundamentals."

This course will be offered in 2020-21, and in alternating years thereafter.

PSYCHOLOGY (PSY)

PSY 1400. INTRODUCTION TO PSYCHOLOGICAL SCIENCE.
Cat. I
Psychological science is the experimental study of human thought and behavior. Its goal is to contribute to human welfare by developing an understanding of why people do what they do. Experimental psychologists study the entire range of human experience, from infancy until death, from the most abnormal behavior to the most mundane, from the behavior of neurons to the actions of nations. This course offers a broad introduction to important theories, empirical findings, and applications of research in psychological science. Topics will include: use of the scientific method in psychology, evolutionary psychology, behavioral genetics, the anatomy and function of the brain and nervous system, learning, sensation and perception, memory, consciousness, language, intelligence and thinking, life-span development, social cognition and behavior, motivation and emotion, and the nature and treatment of psychological disorders.

PSY 1401. COGNITIVE PSYCHOLOGY.
Cat. I
This course is concerned with understanding and explaining the mental processes and strategies underlying human behavior. The ways in which sensory input is transformed, reduced, elaborated, stored, and recovered will be examined in order to develop a picture of the human mind as an active processor of information. Topics will include perception, memory, problem-solving, judgment and decision making, human-computer interaction, and artificial intelligence. Special attention will be paid to defining the limitations of the human cognitive system. Students will undertake a project which employs one of the experimental techniques of cognitive psychology to collect and analyze data on a topic of their own choosing.

Suggested background: PSY 1400.

PSY 1402. SOCIAL PSYCHOLOGY.
Cat. I
Social psychology is concerned with how people think about, feel for, and act toward other people. Social psychologists study how people interact by focusing on the individual (not society as a whole) as the unit of analysis, by emphasizing the effect on the individual of the situation or circumstances in which behavior occurs, and by acquiring knowledge through empirical scientific investigation. This course will examine the cause of human behavior in a variety of domains of social life. Topics will include, but not be limited to, person perception, attitude formation and change, interpersonal attraction, stereotyping and prejudice, and small group behavior. Special attention will be given to applied topics: How can the research methods of social psychology be used to help solve social problems? Students will work together in small groups to explore in depth topics in social psychology of their own choosing.

Suggested background: PSY 1400.

PSY 1404. DEVELOPMENTAL PSYCHOLOGY.
Cat. II
This course surveys human development from conception to death, with an emphasis on the scientific analysis of developmental patterns. The course will cover the biological, cognitive, emotional, social, personality, linguistic, and moral development of the individual at all stages. Students may not receive credit for PSY140X and PSY 1404.

Recommended background: An introductory background in psychological science or experimental methods (PSY 1400).

Students may not receive credit for both PSY 140X and PSY 1404.

Some sections of this course may be offered as Writing Intensive (WI).

PSY 1412. MENTAL HEALTH.
Cat. II
This course will introduce the wide variety of psychological disorders that exist in society (personality, anxiety, mood, psychotic, etc.). For each disorder discussed, possible causes, symptoms, preventions, and treatments will be examined. The course will cover psychopathologies throughout the entire spectrum of the lifespan (infancy to adulthood). Empirical research on understanding, diagnosing, and treating the different disorders will be emphasized.

Suggested background: Introductory psychology (PSY 1400 or equivalent).

Students may not receive credit for both PSY 1412 and PSY 141X.

PSY 1504. STRATEGIES FOR IMPROVING COGNITIVE SKILLS.
Cat. I
Life experience provides us with little insight into the basic workings of our own minds. As a result, we tend to approach many of the important problems and decisions of our professional and personal lives with only a dim awareness of the limitations and capabilities of the human cognitive system and how its performance can be improved. The purpose of this course is (1) to provide students with the basic psychological knowledge needed to understand and evaluate such important cognitive skills as memory, problem solving, decision making, and reasoning and (2) to provide students the practical skills and experience necessary to improve and assess their cognitive performance. Topics will include but not be limited to memory improvement, study skills, effective problem solving techniques, creativity, numeracy, making effective choices, risky decision making, dynamic decision making, intelligent criticism of assumptions and arguments, and evaluating claims about the mind.

Suggested background: PSY 1400.

PSY 2401. THE PSYCHOLOGY OF EDUCATION.
Cat. II
This course is concerned with the learning of persons in educational settings from pre-school through college. Material in the course will be organized into five units covering a wide range of topics: Unit 1: Understanding Student Characteristics - Cognitive, Personality, Social, and Moral Development; Unit 2: Understanding the Learning Process - Behavioral, Humanistic, and Cognitive Theories of Learning; Unit 3: Understanding Motivation to Learn; Unit 4: Understanding Student Diversity - Cultural, Economic, and Gender Effects upon Learning; Unit 5: Evaluating Student Learning - Standardized Tests, Intelligence, Grades, and other Assessment Issues. Students planning IQPs in educational settings will find this course particularly useful. Instructional methods will include: lecture, discussion, demonstration, and project work. Course will also focus on current issues in technological education and international higher education.

Recommended background: PSY 1400 or PSY 1401.

This course will be offered in 2019-20, and in alternating years thereafter.

PSY 2406. CROSS-CULTURAL PSYCHOLOGY: HUMAN BEHAVIOR IN GLOBAL PERSPECTIVE.
Cat. II
This course is an introduction to the study of the ways in which social and cultural forces shape human behavior. Cross-Cultural psychology takes a global perspective of human behavior that acknowledges both the uniqueness and interdependence of peoples of the world. Traditional topics of psychology (learning, cognition, personality development) as well as topics central to social psychology, such as intergroup relations and the impact of changing cultural settings, will be explored. Cultural influences on technology development and transfer, as they relate to and impact upon individual behavior, will also be investigated. Students preparing to work at international project centers, International Scholars, and students interested in the global aspects of science and technology will find the material presented in this course especially useful.

Recommended background: PSY 1400 or PSY 1402.

This course will be offered in 2020-21, and in alternating years thereafter.

PSY 2407. PSYCHOLOGY OF GENDER.
Cat. II
This course will provide an overview of the psychological study of gender and will utilize psychological research and theory to examine the influence of gender on the lives of men and women. This course will examine questions such as: What does it mean to be male or female in our society and other societies? How do our constructs of gender develop over our life span? How does our social world (e.g., culture, religion, media) play a role in our construction of gender? and What are the psychological and behavioral differences and similarities between men and women?

Recommended background: PSY 1400 or PSY 1402.

This course will be offered in 2019-20, and in alternating years thereafter.

PSY 2408. HEALTH PSYCHOLOGY.
Cat. II
In h ealth psychology, we will review global and domestic health-related problems to discuss the links between health and psychology and discuss potential interventions. Health psychology is interdisciplinary in nature and relevant to students interested in health-related topics whether from a psychological, biological, biomedical, global, or preventative measures. Major health problems will be discussed: for example, AIDS is the number one cause of death worldwide; obesity (in children and adults) is a growing epidemic; the aging U.S. population will cause unprecedented health needs. Finally, stress infiltrates chronic health outcomes such as cancer, diabetes, and cardiovascular disease. We will also review what 'positive health' means including nutrition, exercise, social support, managing stress, and habits for maintaining good health.

Students will engage in research-based learning when considering psychological, cultural, and biological interventions for real world health crises.

Recommended background: Introduction to Psychological Science (PSY 1400) and/or Social Psychology (PSY 1402).

PSY 2410. SCHOOL PSYCHOLOGY.
Cat. II
School psychology focuses on understanding children and adolescents' mental health, behavioral health and learning needs in order to work with educators and parents to help students succeed academically and socially. This course will provide an overview of the field of school psychology, drawing from educational, developmental, and cognitive research. Students will critically examine the theoretical, methodological, and practical approaches to understanding how in and out of school interventions and contexts influence the academic, social, and emotional development of children. Topics will include school readiness and transitions, behavioral and self-regulatory skills, socio-cultural diversity and skill gaps, assessment tools and classification, teacher-child interactions, and school- based interventions that promote positive development. This course differs from PSY 2401: They Psychology of Education in that it focuses on school systems rather than education more broadly. Students planning IQPs in educational settings will find this course particularly useful.

Recommended background: Introduction to Psychological Science (PSY 1400), Cognitive Psychology (PSY 1401), and/or The Psychology of Education (PSY 2401), or an approved equivalent.

PSY/MU 2501. MUSIC AND MIND.
Cat. I
How are we able to distinguish instruments, timbres and rhythms from the intertwined sonic stream presented by the world? How do we organize these elements in time to create rhythms, melodies, phrases and pieces? How do perception and memory interact to allow us navigate a musical work? We will explore these questions by considering the cognitive and perceptual processes that shape our musical experience. Topics will include event distinction, temporal perception, hierarchical organization, perceptual grouping, expertise, memory and categorization. We will illustrate these ideas in musical contexts by listening to a variety of musical works. We will consider how psychological principles are applied to music technologies, such as compression algorithms, mixing methodologies and the field of music information retrieval. We will consider experiments that focus on some of these topics to further our understanding about how we experience music.

Note: Students that received credit for MU 202X may not receive credit for MU 2501. Students also may not receive credit for both MU 2501 and PSY 2501. This course can count for either the HUA or the SSPS requirement, but it cannot double count for both the HUA and SSPS graduation requirements.

Recommended background: Fundamentals of Music I and/or Fundamentals of Music II.

PSY 2502. PSYCHOPHYSIOLOGY.
Cat. II
"Mind-Body" connection may be an overused term, but in social science research, there is a growing use of physiological measures to infer psychological states, that is, to "get under the skin." Sophisticated physiological measures are now commonly used to examine psychological processes. We will review the biological measures (e.g., sympathetic and parasympathetic nervous system, facial electromyography, and neuroendocrine monitoring) that can provide insight into emotional, cognitive, attitudinal, and motivational responses to psychological events, such as social rejection or helping others. The primary focus of the course is to investigate how psychophysiology can be applied to the study of social psychological phenomena, specifically (e.g., how can prejudice or related biases in attitudes be measured 'under the skin', social evaluation, lie detection, emotion regulation, stress of conformity, the benefits of prosocial behavior).

Recommended background: Introduction to Psychological Science (PSY 1400), Social Psychology (PSY 1402), and/or Experimental Design and Analysis (PSY 3500).

PSY 2504. HUMAN SEXUALITY.
Cat. II
Do women have less sexual arousal than men? How do religion, laws, and public policies influence perceptions of sex? What effects does pornography have on sexual attitudes and behaviors? How widespread is sexual and domestic violence?

In this class, we will explore questions relating to our sexuality. Human sexuality is the study of the biological, evolutionary, social, cultural, and political perspectives relating to sex and the meaning behind "masculinity", "femininity", and "asexual" or "genderqueer". We will discuss topics such as: gender roles, transgender, sexual orientation, the anatomy and physiology of the act of sex, relationships, sexual aggression, pornography, contraception, pregnancy, abortion, sexuality and aging, and the role of religion, law, policies, and cultural. We will think about how our sexuality influences how we think and act in the world around us. We will examine sexuality within the United States and throughout the world. This course is designed to increase awareness and sensitivity to sexuality and issues relating to it. Discussions in class will be candid and on sensitive and controversial topics.

Recommended background: Introduction to Psychological Science (PSY 1400), Social Psychology (PSY 1402), and/or Psychology of Gender (PSY 2407).

PSY 3000. PSYCHOLOGY AND LAW.
Cat. II
How does the courtroom work and where does psychology come into play? Is it really "innocent until proven guilty"? Do people confess to crimes they never committed? How accurate are eyewitnesses? In this course, we will discuss and examine questions like these and many more. This course examines empirical research in the interface of psychology and law. We will learn about standard practices in the criminal justice system and empirical psychological research devoted to understanding these practices. As a discussion-based course, we will tackle topics such as: courtroom procedures, confessions, death penalty, deception, decision making, deliberations, eyewitnesses, expert testimony, jury selection, memory, police, and pretrial publicity. We will also explore how and when psychologists can impact legal guidelines and policies.

Recommended background: Introduction to Psychological Science (PSY 1400), Social Psychology (PSY 1402) and/or Cognitive Psychology (PSY 1401). Courses in Government and Policy Studies will also be beneficial.

PSY 3500. EXPERIMENTAL DESIGN AND ANALYSIS.
Cat. II
In this course, students will learn about different processes used when designing experiments. In addition, they will learn about different analyses that can be used based on different experimental designs. Students will design and run a simple experiment in the course. In addition, students will analyze the data and present their findings. Topics covered in the course include experimental design, experimental methods, ethical issues related to human participants research, use of statistical analyses and programs to analyze data, and hypothesis testing.

Recommended background: Familiarity with the fundamentals of psychological science and cognitive or social psychology (PSY 1400 and PSY 1401 or PSY 1402, or equivalent).

Students may not receive credit for both SS 2400 and PSY 3500.

This course will be offered in 2019-20 and in alternate years thereafter.

Psychology Research Courses

PSY 2900. INTRODUCTION TO RESEARCH IN PSYCHOLOGICAL SCIENCE.
ISU (Credits are variable from 1/6-1/3 unit)
This course provides an opportunity for students learn how to conduct psychological research in a research laboratory in psychological sciences. Recommended background: a base understanding of Psychological Science (PSY 1400, PSY 1401, PSY 1402, or equivalent). Permission of the instructor is necessary to register. This course may be repeated for credit.

PSY 3900. RESEARCH IN PSYCHOLOGICAL SCIENCE.
ISU (Credits are variable from 1/6-1/3 unit)
This course provides an opportunity for students to conduct psychological research in a research laboratory in psychological sciences. Recommended background: a fundamental understanding of psychological science research (PSY 2900, PSY 3500, or equivalent). Permission of the instructor is necessary to register. This course may be repeated for credit.

PSY 4900. ADVANCED RESEARCH IN PSYCHOLOGICAL SCIENCE.
ISU (Credits are variable from 1/6-1/3 unit)
This course provides an opportunity for students to conduct advanced psychological research in a research laboratory in psychological sciences. Recommended background: an advanced understanding of psychological science research (PSY 3500, PSY 3900, or equivalent). Permission of the instructor is necessary to register. This course may be repeated for credit.

Psychology Special Topics Courses

PSY 1800. SPECIAL TOPICS IN PSYCHOLOGICAL SCIENCE.
Cat II (Credits will be assigned by the instructor ranging from 1/6-1/3 unit)
This course provides an opportunity for students with little to no background in psychological science to learn about a special topic within Psychological Science. This course may be repeated for different topics.

PSY 2800. SPECIAL TOPICS IN PSYCHOLOGICAL SCIENCE.
Cat II (Credits will be assigned by the instructor ranging from 1/6-1/3 unit)
This course provides an opportunity for students with some background and interest in psychological science to learn about a special topic within Psychological Science. Recommended background: An introductory background in psychological science (PSY 1400, PSY1401, PSY 1402, or equivalent). This course may be repeated for different topics.

PSY 3800. SPECIAL TOPICS IN PSYCHOLOGICAL SCIENCE.
Cat II (Credits will be assigned by the instructor ranging from 1/6-1/3 unit)
This course provides an opportunity for students with a solid background and interest in psychological science to learn about a special topic within Psychological Science. Recommended background: one 2000-level Psychological Science courses (or equivalent). This course may be repeated for different topics.

PSY 4800. SPECIAL TOPICS IN PSYCHOLOGICAL SCIENCE.
Cat II (Credits will be assigned by the instructor ranging from 1/6-1/3 unit)
This course provides an opportunity for students with a strong background and interest in psychological science to learn about a special topic within Psychological Science. Recommended background: two 2000 and/or 3000 level Psychological Science courses. This course may be repeated for different topics.

SYSTEM DYNAMICS (SD)

SD 1510. INTRODUCTION TO SYSTEM DYNAMICS MODELING.
Cat. I
The goal of this course is to provide students with an introduction to the field of system dynamics computer simulation modeling. The course begins with the history of system dynamics and the study of why policy makers can benefit from its use. Next, students systematically examine the various types of dynamic behavior that socioeconomic systems exhibit and learn to identify and model the underlying nonlinear stock-flow-feedback loop structures that cause them. The course concludes with an examination of a set of well-known system dynamics models that have been created to address a variety of socioeconomic problems. Emphasis is placed on how the system dynamics modeling process is used to test proposed policy changes and how the implementation of model-based results can improve the behavior of socioeconomic systems.

SD 2520. MODELING ECONOMIC AND SOCIAL SYSTEMS.
Cat. II
The purpose of this course is to prepare students to construct original system dynamics computer simulation models of economic and social systems from real world situations. They are coached to experiment with these models to understand unintended consequences of policy and to design effective policy interventions. Such a modeling process can be used to examine the possible impacts of policy changes and technological innovations on socioeconomic systems. The curriculum in this course covers a detailed examination of the steps of the system dynamics modeling process: problem identification (including data collection and analysis), feedback structure conceptualization, model formulation, model testing and analysis, model documentation and presentation, and policy implementation, illustrated by examples from business, economy and social systems. This course together with either SS1505 or SD1510 can provide the basic background for the students to use system dynamics in their IQP/MQP projects. Students will not be granted credit for both SD1520 and SD2520.

Recommended background: Fundamental systems thinking concepts as presented in SS1505, SD1510, or permission of the instructor.

SD 2530. ADVANCED TOPICS IN SYSTEM DYNAMICS MODELING.
This course focuses on advanced issues and topics in system dynamics computer simulation modeling. A variety of options for dealing with complexity through the development of policy models, large-scale models and the partitioning of complex problems are discussed. Topics include model building, model validation, model analysis, the use of summary statistics and sensitivity measures, and policy design. The application of system dynamics to theory building and social policy are also reviewed.

Recommended background: SD 1510.

SD 3550. SYSTEM DYNAMICS SEMINAR.
This special topics course is conducted as a research seminar, with many sessions being reserved for student presentations. Students will read, evaluate, and report on research papers representing the latest developments in the field of system dynamics. Classical system dynamics models may also be replicated and discussed. Students will complete projects that address specific problems using the system dynamics method.

Recommended background: SD 1510.

SOCIOLOGY (SOC)

SOC 1202. INTRODUCTION TO SOCIOLOGY AND CULTURAL DIVERSITY.
Cat. I
This course encourages students to explore how a sociological toolkit may be used to examine the impetus for social and historical changes and the effect such changes have on how individuals live, work, and find their place in this world. It operates from the premise that individual lives are not just personal but social—as humans we are shaped by the societies in which we live and the social forces at work within them. Major theoretical perspectives and concepts will be discussed over the course of the semester with primary emphasis on the roles that culture, dimensions of inequality and social change play in shaping individual lives. Students will also explore the influence that social institutions such as the family, religion, education, healthcare, government, economy, and environment have on how humans function within society.

GENERAL SOCIAL SCIENCE (SS)

SS 1505. GAMES FOR UNDERSTANDING COMPLEXITY.
Cat. I
This course addresses the theory and practice of developing solutions to complex social and environmental problems through interaction with roleplaying games and computer simulations designed to promote learning and improve decision-making. By interacting with a selection of games and case studies, students will learn to recognize the systemic causes of complex social and environmental problems and gain experience developing and using simulations to test policies for creating sustainable futures. Special attention will be given to appropriate modeling practices and the design of simulation experiments. The course is run in a laboratory format in which students work in groups to play games, develop simulation models and present them to the class for feedback before they revise and refine their work iteratively for final evaluation.
Recommended background: None
Students who completed SS 150X cannot receive credit for SS 1505.

SS/ID 2050. SOCIAL SCIENCE RESEARCH FOR THE IQP.
Cat. I
This course is open to students accepted to off-campus IQP centers and programs. The course introduces students to research design, methods for social science research, and analysis. It also provides practice in specific research and field skills using the project topics students have selected in conjunction with sponsoring agencies. Students learn to develop social science hypotheses based upon literature reviews in their topic areas and apply concepts drawn from social psychology, anthropology, sociology, economics and other areas as appropriate. Students make presentations, write an organized project proposal, and develop a communication model for reporting their project findings.

SOCIETY/TECHNOLOGY STUDIES

STS 1200. FUNDAMENTALS OF GLOBAL HEALTH.
Cat. I
The focus of global health research and practice is improving the overall health and health equity of all people worldwide. In this course, we will use an interdisciplinary approach to explore the major biological, social, political, environmental and economic determinants of health. We will analyze the dual burden of communicable and non-communicable disease facing the world's populations including study of current health systems, global health practices and priorities as well as major organization and institutional players. Class sessions will consist of lecture, intensive small group discussion, and global health case analyses. After successful completion of this course, students will be able to explain the basic principles of public health; discuss the determinants of health; describe how globalization has changed the patterns of the spread of disease and the methods needed to control disease; evaluate the complex, multi-faceted links between health, social and economic factors; and identify critical issues in the delivery of health care services, with a particular emphasis on challenges faced with regard to different cultural and economic settings.

STS 4000. SENIOR SEMINAR IN GLOBAL PUBLIC HEALTH.
Cat. II
The course is designed to integrate each student's educational experience and interests in Global Public Health, (e.g., core global public health courses, specializations, and experience). Through seminar discussions and writing assignments students will critically reflect on what they learned in their previous courses and project experiences. In teams, students will prepare a final capstone paper and presentation that critically engages their educational experience in global public health and anticipates how their courses and experiences will translate into their future personal and professional. The course is especially designed as the capstone seminar for Global Public Health minors, but is also open to non-minors.
Recommended background: previous courses in global public health, and completion or concurrent registration with a global public health-related MQP, IQP or ISU.
This course will be offered in 2019-20, and in alternating years thereafter.

UNIVERSITY POLICIES AND PROCEDURES

SECTION 4

University Policies and Procedures 208
Grades 208
Grade Appeal and Grade Change Policy 209
Transfer Credit 211
Graduation with Honors 211
Commencement 212
Early Completion 212
Designation of Major Area of Study 212
Double Major 212
Designation of Class Year 212
Academic Honesty Policy 212
Guidelines for the Determination of Satisfactory Academic Progress, Academic Warning, Academic Probation and Academic Suspension 214
Administrative Obligations and Holds 215
Directory Information and Release of Information 215
Office of the Registrar 216
Part-Time Degree Students 219
Non-Degree Students 219

GRADES

DISTRIBUTION OF GRADES

Academic grades of undergraduate students may be released to parent(s) of a student claimed as a dependent for tax purposes. WPI presumes that all undergraduate students are dependents of their parent(s) unless they file a Declaration of Independent Status petition form with the Registrar's Office. These forms are available in the Registrar's Office. After the Registrar's Office receives a Declaration of Independent Status petition form from an undergraduate student, the Office will not release the student's academic grades to the parent(s) of such student until such time as the student rescinds their Declaration, in writing filed with the Registrar's Office, or his/her parent(s) provide acceptable proof of tax-dependent status to the Registrar's Office.

GRADING SYSTEM

Projects: The following term grades are possible: A, B, C, SP (Satisfactory Progress), NAC (Not Acceptable) and NR (No record).

Courses: The following grades are possible: A, B, C, NR, and I (Incomplete). An instructor may also assign an "I" in an Independent Study course. AT (attended) is used to denote participati on in seminars or college-sponsored programs.

Students such as Consortium (CO), nondegree-seeking students, and Graduate students will receive traditional A, B, C, D, F, Withdrawal and Pass/Fail grades.

GRADES FOR COMPLETION OF DEGREE REQUIREMENTS

The overall evaluation of degree requirements (for the MQP, the IQP and the Humanities and Arts Requirement) will be graded in the student's respective grade system. The transcript will contain an abstract describing the content of the completed project.

NO RECORD (NR)

The NR (No Record) grade is assigned by a faculty member for course or project work for which credit has not been earned. This grade applies to PLAN students (admitted, degree-seeking) only. The NR grade does not appear on the students' transcripts or grade reports.

INCOMPLETE (I)

An I grade, when assigned, will be changed to NR after one term unless extended in writing by the instructor to the Registrar's Office. The I grade is not assigned for Qualifying Projects.

SATISFACTORY PROGRESS (SP)

In project work (IQP, MQP only) extending beyond one term for which a grade is not yet assigned, an interim grade of SP (Satisfactory Progress) may be used on grade sheets. In such cases, the SP evaluation will count as units earned toward meeting the 15-unit rule, the distribution requirements, and the minimum standards for satisfactory academic progress. SP grades remain on the transcript until changed to the final grade as submitted on the Completion of Degree Requirement Form or through the grade change form procedure.

OTHER GRADES

A ? or Q signifies a grade that has not been submitted.

QUALIFYING PROJECT GRADING

The Faculty of WPI has endorsed the following grading guidelines for qualifying project activity:

1. Each term a student is registered for a qualifying project, the student receives a term grade reflecting assessment of his or her accomplishments for that term.
2. Upon completion of a project, each student will receive an overall project grade (also known as the "CDR grade," since it certifies completion of the degree requirement) reflecting his or her individual overall accomplishments for the project.
3. The term grades and the overall project grade reflect both the ***products*** of the project (e.g., results, reports, etc.) and also the ***process*** by which they were attained. The term grades and the overall project grade may be different.

The following are some characteristics that faculty should use in communicating expectations and evaluating the quality of each student's project work.

The degree to which the student:

- developed effective or creative goals or approaches,
- demonstrated initiative and originality,
- showed depth and critical thought in analysis,
- produced high quality results,
- took the lead in discussion, planning, and analysis,
- produced a clear, professional-level report with excellent drafts along the way,
- anticipated work that needed to be done and completed it in a timely manner, and
- worked to advance the success of the team.

For both terms and overall project, the available grades and interpretations are:

A: This grade denotes *excellent work* that attains all of the project goals and learning outcomes. The product and process of this work meet all of the expectations and exceed them in several areas.

B: This grade denotes *consistently good work* that attains the project goals and learning outcomes. The product and process of this work meet but generally do not exceed all of the expectations.

C: This grade denotes *acceptable work* that partially attains project goals and learning outcomes. The product and process of this work meet some but not all expectations.

SP: This grade denotes *satisfactory progress* and certifies sufficient accomplishments to earn credit for that term. Faculty who assign this grade should provide clear feedback to the student regarding his or her progress during the term. The use of the SP grade is discouraged except in circumstances where the faculty member is unable to judge the quality of the work, yet can attest that the granting of credit is appropriate. This is a temporary grade and must be replaced by a permanent grade consistent with the criteria outlined above by, if not before, the end of the project.

NR: This grade denotes work that did not attain the project goals or learning outcomes and is *insufficient for registered credit*. Both product and process were inconsistent with acceptable project work at WPI as outlined above.

NAC: This grade is reserved for *performance that is unacceptable*. It might mean that a student's performance (or lack of it) has seriously impeded group progress, or it has embarrassed the group, a project sponsor, or WPI. Note that this grade remains on the transcript.

4. Project goals should be established and clearly articulated early in the project. This may be done in the form of a formal project proposal. Learning outcomes for the qualifying projects have been established by the faculty and are published in the undergraduate catalog.
5. Project advisors should clearly convey in writing their expectations for learning and performance to project students at the start of the project, and provide students with substantive feedback on a regular basis during the project.

CUMULATIVE POINT AVERAGE

WPI does not maintain a Cumulative Grade Point Average for undergraduate students. A student who needs a cumulative point average for external use may apply to the Registrar and receive a numerical equivalent. This information is usually provided only for students applying to graduate or professional schools when the application process requires a translation. Cumulative point averages will not be printed on student's transcripts nor shall class rankings be developed from them.

When requested by the student, the numerical equivalent of the cumulative point average will be based on a point assignment of A = 4.0, B = 3.0, C = 2.0 while DIST and AC grades will be 4.0 and 2.75 respectively.

DEAN'S LIST

The Dean's List is created and published twice a year: in January to review student work completed during the AB terms and in May to review student work completed during the CD terms. To be named to the Dean's List a student must:

Complete 4/3 units with grades of A's, and at least an additional 2/3 units with grades of B or above.

For example, a student with 4A's, 2B's and 1C (or 1 NR) in 1/3-unit courses during a semester is eligible for the Dean's List. Credits earned in Physical Education, Military Science, and Air Force Aerospace Studies are not used in the evaluation for the Dean's List. For the purposes of determining the Dean's List only, an SP grade for project work will be considered a B grade. The Dean's List recognizes outstanding work completed during the most recent semester. Student requests to re-evaluate their eligibility for the Dean's List due to a grade change after the semester review is completed will be considered only in unusual circumstances and at the discretion of the Dean of Undergraduate Studies.

GRADE APPEAL AND GRADE CHANGE POLICY

The purpose of the Grade Appeal Policy is to provide the student with a safeguard against receiving an unfair final grade, while respecting the academic responsibility of the instructor. Thus, this procedure recognizes that,

- Every student has a right to receive a grade assigned upon a fair and unprejudiced evaluation based on a method that is neither arbitrary nor capricious; and,
- Instructors have the right to assign a grade based on any method that is professionally acceptable, submitted in writing to all students, and applied equally.

Instructors have the responsibility to provide careful evaluation and timely assignment of appropriate grades. Course and project grading methods should be explained to students at the beginning of the term. WPI presumes that the judgment of the instructor of record is authoritative, and the final grades assigned are correct.

A grade appeal shall be confined to charges of unfair action toward an individual student and may not involve a challenge of an instructor's grading standard. A student has a right to expect thoughtful and clearly defined approaches to course and project grading, but it must be recognized that varied standards and individual approaches to grading are valid. The grade appeal considers whether a grade was determined in a fair and appropriate manner; it does not attempt to grade or re-grade individual assignments or projects. It is incumbent on the student to substantiate the claim that his or her final grade represents unfair treatment, compared to the standard applied to other students. Only the final grade in a course or project may be appealed. In the absence of compelling reasons, such as clerical error, prejudice, or capriciousness, the grade assigned by the instructor of record is to be considered final.

In a grade appeal, only arbitrariness, prejudice, and/or error will be considered as legitimate grounds for an appeal.

Arbitrariness: The grade awarded represents such a substantial departure from accepted academic norms as to demonstrate that the instructor did not actually exercise professional judgment.

Prejudice: The grade awarded was motivated by ill will, and is not indicative of the student's academic performance.

Error: The instructor made a mistake in fact.

This grade appeal procedure applies only when a student initiates a grade appeal and not when the instructor decides to change a grade on his or her own initiative. This procedure does not cover instances where students have been assigned grades based on academic dishonesty or academic misconduct, which are included in WPI's Academic Honesty Policy. Also excluded from this procedure are grade appeals alleging discrimination, harassment or retaliation in violation of WPI's Sexual Harassment Policy, which shall be referred to the appropriate office at WPI as required by law and by WPI policy.

The Grade Appeal Procedure strives to resolve a disagreement between student and instructor concerning the assignment of a grade in an expeditious and collegial manner. The intent is to provide a mechanism for the informal discussion of differences of opinion, and for the formal adjudication by faculty only when necessary. In all instances, students who believe that an appropriate grade has not been assigned must first seek to resolve the matter informally with the instructor of record. If the matter cannot be resolved informally, the student must present his or her case to the Faculty Review Committee before the end of the second week of the term after the disputed grade is received (D term grades may be appealed the following A term). Any exceptions to this deadline for submission of appeal can only be made by the Office of the Provost.

STUDENT GRADE APPEAL PROCEDURE

1. A student who wishes to question a grade must discuss the matter first with the instructor of record within one week after the start of the next regular academic term (A – D) after receiving the grade. Late appeals will only be reviewed at the discretion of the Faculty Review Committee (FRC). In most cases, the discussion between the student and the instructor should suffice and the matter will not need to be carried further. The student should be aware that the only valid basis for grade appeal beyond Step One is to establish that an instructor assigned a grade that was arbitrary, prejudiced, or in error.
2. If the student's concerns remain unresolved after the discussion with the instructor, the student may submit a written request to meet with the appropriate Department Head, within one week of speaking with the instructor. For a grade in a course, independent study, Inquiry Seminar or Practicum, or Major Qualifying Project (MQP), the appropriate person is the instructor's Department Head. For a grade in an Interactive Qualifying Project (IQP), the appropriate person is the Dean of the Interdisciplinary and Global Studies Division (IGSD). If the instructor of record is a Department Head or the Dean of the IGSD, then the student should request to meet with the representative from the Provost's office (the Dean of Undergraduate Studies, or alternative if necessary), who will serve as the appropriate Department Head/Dean in this step. The appropriate Department Head/Dean will meet within one week with the student, and, if he or she believes that the complaint may have merit, with the instructor. After consultation with the Department Head/Dean, the instructor may choose to let the grade remain, to change a course grade, or to petition the Committee on Academic Operations to change a grade for a Degree Requirement (CDR grade for MQP, IQP, or Humanities and Arts Inquiry Seminar or Practicum). The Department Head/Dean will communicate the result of these discussions to the student.
3. If the matter remains unresolved after Step Two, the student should submit a written request within one week to the Provost's Office to request an ad hoc Faculty Committee for Appeal of a Grade. The Provost's representative (the Dean of Undergraduate Studies, or alternate) will meet with the student, and will ask the FRC to appoint the ad hoc Committee for Appeal of a Grade. The Chair of the FRC will select the members of the ad hoc committee and serve as its non-voting chair. The ad hoc committee for all undergraduate appeals will be composed of three FRC members. Appointees to the ad hoc committee must not have any apparent conflicts of interest with the student or instructor of record. The Chair of the FRC requests a written statement from the student and a written response from the instructor. The ad hoc committee examines the written information and may gather additional information as it sees fit.
4. Through its inquiries and deliberations, the ad hoc committee is charged to determine whether the grade was assigned in a fair and appropriate manner, or whether clear and convincing evidence of arbitrariness, prejudice, and/or error might justify changing the grade. The ad hoc committee will make its decisions based on a majority vote.
5. If the ad hoc committee concludes that the grade was assigned in a fair and appropriate manner, the ad hoc committee will report its conclusion in writing to the student and instructor. This decision of the ad hoc committee is final and not subject to appeal.
6. If the ad hoc faculty committee determines that compelling reasons exist for changing the grade, it would request that the instructor make the change, providing the instructor with a written explanation of its reasons. At this point, the instructor may change the grade. If the instructor declines to change the grade, he or she must provide a written explanation for refusing. If the ad hoc faculty committee concludes that the instructor's written explanation justifies the original grade, the ad hoc committee will report this in writing to the student and instructor and the matter will be closed. If the ad hoc faculty committee concludes that it would be unjust to allow the original grade to stand, the ad hoc committee will then determine what grade is to be assigned. The new grade may be higher than, the same as, or lower than the original grade. Having made this determination, the three members of the committee will sign the grade change form and transmit it to the Registrar. The instructor and student will be advised of the new grade. Under no circumstances may persons other than the original faculty member or the review committee change a grade. The written records of these proceedings will be filed in the student's file in the Registrar's Office.

FACULTY GRADE CHANGE PROCEDURE

The Student Grade Appeal Procedure affirms the principle that grades should be considered final. The principle that grades for courses or projects should be considered final does not excuse an instructor from the responsibility to explain his or her grading standards to students and to assign grades in a fair and appropriate manner. The appeal procedure also provides an instructor with the opportunity to change a grade for a course or project on his or her own initiative. The appeal procedure recognizes that errors can be made and that an instructor who decides that it would be unfair to allow a final grade to stand due to error, prejudice or arbitrariness may request a change of grade for a course or project without the formation of an *ad hoc* committee. An instructor may request a grade change in one of two ways. First, for courses, an instructor may submit a course grade change via BannerWeb to the Registrar at any time prior to a student's graduation. Second, for Degree Requirements (MQP, IQP), an instructor must submit a petition to the Committee on Academic Operations (CAO) to change the grade.

TRANSFER CREDIT

TRANSFER CREDIT BEFORE MATRICULATION TO WPI

After a student has been accepted and final transcripts received, the Office of Admissions coordinates the formal evaluation of credit accepted towards a WPI degree. Courses taken at regionally accredited post-secondary institutions that are comparable to courses offered at WPI will be reviewed for course content and level by the WPI department offering the comparable course. Only those courses in which the transfer student received a grade of C or better will be evaluated for possible transfer credit. Please note vocational, correspondence, pre-college or review courses are not transferable. Also, non-credit CEU courses, adult enrichment or refresher courses, and CLEP examinations are not recognized for transfer credit.

TRANSFERING CREDIT AFTER MATRICULATION TO WPI

If you are currently a WPI student who wishes to take courses at a regionally accredited post-secondary institution, you must obtain a WPI Transfer Credit Authorization form from the Registrar's Office. This form and the course description must be taken to the WPI department head or transfer faculty approved by the department head for approval **before** the course is taken. On the form, the department head specifies a minimum grade for transfer. This minimum grade depends on the institution at which the course is taken and how critical the course is to the department. Please note, most departments do **not** accept on-line courses for transfer credit. Confirm this with the relevant department before registering and completing any on-line courses. Courses that have not been pre-approved may not receive transfer credit. The completed form must be filed in the Registrar's Office before taking the course. After successful completion of the course, an official transcript should be sent to WPI. Students can check the web for posting of credit. Please note vocational, correspondence, pre-college or review courses are not transferable. Also, noncredit CEU courses, adult enrichment or refresher courses, and CLEP examinations are not recognized for transfer credit.

TRANSFERRING CONSORTIUM COURSES

Courses taken through the consortium do not need to be transferred into WPI. Courses will automatically be part of the WPI transcript. However, if you are taking the course through the consortium to fulfill a WPI distribution requirement, you should check with the Registrar's Office to see if the course has been pre-approved to satisfy the requirement. If not, you will need approval from the relevant department head before taking the course.

To apply for approval of a consortium course to satisfy a specific WPI distribution requirement, a student must obtain a WPI Transfer Credit Authorization form from the Registrar's Office. This form and the course description must be taken to the WPI department head for approval before the course is taken. The WPI department head decides whether the proposed course meets the department distribution requirement. If it does, the department head specifies on the form a minimum grade for satisfying the distribution requirement. This minimum grade depends on the institution at which the course is taken and how critical the course is within the department. Courses that have not been pre-approved may receive WPI elective credit. The complete form must be filed in the Registrar's Office before taking the course.

GRADUATION WITH HONORS

For all degree candidate students graduating from WPI after May 1, 2011, graduation honors will be determined as follows:

Graduation With High Distinction
An *A* grade on all *four* of the following:

- MQP
- IQP
- Inquiry Seminar/Practicum
- Eight units of work registered at WPI (exclusive of PE and of the MQP, IQP and the Inquiry Seminar/Practicum component of the Humanities and Arts Requirement).

Graduation With Distinction
A grade of *A* on the following criteria:

- MQP
- IQP
- Inquiry Seminar/Practicum
- Four units of work registered at WPI (exclusive of PE and of the MQP, IQP and the Inquiry Seminar/Practicum component of the Humanities and Arts Requirement).

or
a grade of *A* on the following criteria:

- Two of the three projects: MQP, IQP and the Inquiry Seminar/Practicum
- Six units of work registered at WPI (exclusive of PE and of the MQP, IQP and the Inquiry Seminar/Practicum component of the Humanities and Arts Requirement).

For all degree candidate students graduating from WPI from May 1, 1986, to June 1, 2010, graduation honors will be determined as follows:

Graduation with High Distinction
An A or DIST grade on any four of the following:

- MQP
- IQP
- Inquiry Seminar/Practicum
- Six units of work registered at WPI (exclusive of PE and of the MQP, IQP, or the Inquiry Seminar/Practicum component of the Humanities and Arts Requirement).

Graduation with Distinction
An A or DIST grade on any three of the above.

HONORS FOR DOUBLE MAJORS

If a student completes two majors, the student is awarded a degree with "Distinction" or "High Distinction" if the student meets the criteria above in either or both majors; if both awards are received, the degree is awarded with "High Distinction."

COMMENCEMENT

COMMENCEMENT POLICY

The policy for allowing certain undergraduate students who have not completed all degree requirements to participate in Commencement exercises is:

1. Undergraduate students who have not met all degree requirements will be eligible to participate in Commencement exercises only if *all of the following* are true:
   a. At the end of D term, the student is within 1/3 unit of one activity in all requirements for graduation.
   b. The student has completed at least 2 of the 3 WPI Project Requirements (Humanities and Arts Requirement, IQP, and MQP).
2. Undergraduate students who meet these conditions will be permitted to participate in Commencement exercises but will not receive their diploma. The names of such students will **not** be included in the Commencement program. The actual degree will be conferred only after all degree requirements have been completed.
3. All WPI undergraduate students will be notified of these policies and procedures each B term.
4. Undergraduate students seeking an exception to this policy have the right to petition the Committee on Academic Operations for a waiver due to extenuating circumstances. Petitions must be received no later than noon (12 p.m.) the Wednesday before Commencement Day.

EARLY COMPLETION

Students completing 100% of WPI graduation requirements by the end of A-term or C-term will be eligible for a 50% tuition adjustment for the semester of completion. Eligible students must complete the form available in the Registrar's Office and submit by the end of B-term (for C-term completion) or D-term (for A-term completion). Students/responsible parties will be billed for the full semester and then tuition charges will be reduced by 50% once the graduation requirements have been signed off and the student's withdrawal has been officially processed. Qualified students receiving financial aid from WPI will retain 50% of any WPI scholarship, and their loan eligibility will be reviewed on an individual basis. Students living in WPI housing will still be financially responsible for paying the full semester's worth of room and board.

Students are permitted to enroll in a maximum of 4/3 units (12 credits), excluding PE, in either A or C term. Students registered beyond 4/3 units will be charged the overload fee.

DESIGNATION OF MAJOR AREA OF STUDY

Designation of a student's major area of study on the transcript is determined by his or her completion of published academic activity distribution requirements, as well as by the Major Qualifying Project. The authority and responsibility of certification of the disciplinary or interdisciplinary area will lie with the appropriate departmental or IGSD Program Review Committee (PRC) in consultation with the student and his or her academic advisor.

For examples of major areas of study, please see page 8.

DOUBLE MAJOR

DISTRIBUTION REQUIREMENTS

The distribution requirements of each major must be met, but requirements common to both majors may have to be met only once. A minimum of three units of qualifying project work is thus required for fulfillment of the project portion of the double major requirements: one unit in each of the two major areas of study, and one unit of an IQP. See page 7 for details and options.

For students wishing to pursue double majors not involving social science, the program audit for each intended major must be completed and certified by the review committee of each department involved. Academic activities appropriate to both majors may be counted in both majors.

For the policy in the special situation of double majors involving the social sciences, see page 118.

If a student wishes to complete two Interdisciplinary (individually designed) Majors Programs, the double major must be proposed in a single Educational Program Proposal, which must be approved by the student's Program Advisory Committee for each major. The Committees shall ensure that the majors are substantially nonoverlapping.

If a student's double major includes an Interdisciplinary (individually designed) Major Program, the double majors must be described in the Educational Program Proposal for the Interdisciplinary Major.

DESIGNATION OF CLASS YEAR

Class year will normally be designated as year of matriculation plus four with the additional requirement that the accumulation of 34/3 units is necessary for fourth-year status, 22/3 units for third-year status, and 10/3 units for second-year status. The class year of transfer students will be determined on an individual basis. Class year designations will be reviewed at the end of Term E each year and changed if the credit accumulation does not meet the above specifications. After Term E, students may petition to be redesignated in their original class if they meet the minimum unit requirements.

ACADEMIC HONESTY POLICY

Academic honesty is a fundamental principle of learning and a necessary foundation for all academic institutions, particularly those dedicated to independent project-based education, such as WPI. Violations of the principle deny the violators an opportunity to obtain confident command of the material they are credited with knowing, cheat their classmates out of deserved rewards and recognition, debase the institution, and demean the degree that it awards. It is, therefore, a matter of great and mutual concern to all members of the WPI community that a concerted effort be made to maintain high standards of integrity, both to protect the value of the educational process in which we are engaged and to maintain the credibility of the institution.

DEFINITION

Individual integrity is vital to the academic environment because education involves the search for and acquisition of knowledge and understanding, which are, in themselves, intangible. Evaluation of each student's level of knowledge and understanding is a vital part of the teaching process, and requires tangible measures such as reports, examinations, and homework. Any act that interferes with the process of evaluation by misrepresentation of the relation between the work being evaluated (or the resulting evaluation) and the student's actual state of knowledge is an act of academic dishonesty. The following acts are examples of academic dishonesty at WPI:

Fabrication

Examples:

- Altering grades or other official records
- Changing exam solutions after the fact
- Inventing or changing laboratory data
- Falsifying research
- Inventing sources
- Sabotage of another student's work or academic record

Plagiarism

Examples:

- Misrepresenting the work of another as one's own
- Inaccurately or inadequately citing sources including those from the Internet

Cheating

Examples:

- Use of purchased term papers
- Copying on exams, homework, or take-home exams
- Use of unauthorized materials or sources of information such as "cheat sheet," pre-programmed calculator
- Assistance of another person in cases where prohibited

Facilitation

Examples:

- Sharing test questions or answers from an exam with another student
- Letting another student copy a solution to a homework problem, exam, or lab
- Taking an exam for another student
- Assistance in any act of academic dishonesty of another student

RESPONSIBILITIES OF FACULTY MEMBERS AND STUDENTS

Faculty members should outline their policies concerning evaluation procedures and their expectations pertaining to academic integrity at the beginning of each course. Faculty must ensure that student performance is judged solely on the basis of academic work in courses and projects. Because of the differences in disciplines and the type of work involved, faculty interpretation regarding what constitutes academic dishonesty may vary across campus. Since project-based education places a strong emphasis on group work, faculty and students should be particularly attentive to the distinction between group work and individual performance expectations. Faculty and students are responsible for knowing and understanding WPI's policy and procedure for dealing with academic dishonesty. Faculty are encouraged to implement measures designed to minimize or prevent academic dishonesty.

PROCEDURES

The WPI faculty and administration have developed a set of procedures designed to ensure uniform (and fair) treatment of undergraduate or graduate students suspected of academic dishonesty. Students or others who suspect a faculty member of professional dishonesty should consult the academic department head or the provost.

- Faculty shall report to the department chair any suspected act of academic dishonesty.
- The chair shall review cases referred to him/her to determine if there is reason for believing that academic dishonesty may be involved.
- Faculty shall allow the student to continue in the course without prejudice, pending resolution of the case.
- The chair or instructor shall check with the dean or associate dean of students to determine if the student has any record of prior offenses involving academic dishonesty.
- The chair or instructor shall consult with the student involved. If the act of academic dishonesty is admitted and is the first violation of that nature, the chair or instructor may resolve the complaint within the department, provided the penalty is accepted by the student in writing. The maximum penalty that can be applied at the department level is dismissal from a course or a project without credit. In all cases, a signed, written report on the matter, including the action taken, shall be sent to the Dean of Students Office and to the student's Academic Advisor.
- For the second and subsequent violations, the case shall be submitted to the Campus Hearing Board for resolution.
- The Campus Hearing Board shall hear the allegations, following standard procedures for disciplinary hearings established by WPI. The board may impose normal disciplinary sanctions and may recommend loss of any credit or grade for the course or project. If a student is found not responsible on a complaint of academic dishonesty, he/she may not be failed or penalized by the instructor on the grounds of dishonesty. The instructor shall assign a grade based on his or her assessment of the student's mastery of the material being evaluated.
- Disciplinary records for any act of academic dishonesty shall be retained in the Dean of Students Office for two years from the date of graduation or withdrawal from WPI, except when the sanction includes suspension or expulsion. In cases resulting in suspension or expulsion from WPI, disciplinary records shall be kept in perpetuity. Records for cases that are pending completion of the hearing and/or the sanction shall be kept in perpetuity. Judicial records are kept separate from a student's academic records. A student's judicial record may be shared internally as appropriate to determine if a past record exists. Records shall be available to prospective employers and other authorized individuals, in accordance with federal regulations that require written permission from the student involved.

GUIDELINES FOR THE DETERMINATION OF SATISFACTORY ACADEMIC PROGRESS, ACADEMIC WARNING, ACADEMIC PROBATION AND ACADEMIC SUSPENSION

SATISFACTORY ACADEMIC PROGRESS

In order to assist the student, parents, and the academic advisor in determining whether a student is making academic progress, WPI has adopted the following guidelines.

To maintain Satisfactory Academic Progress, a student must:

1. Complete at least 4/3 units of academic work for the fall semester (A and B terms); and
2. Complete at least 4/3 units of academic work for the spring semester (C and D terms).

Note: Air Force Aerospace Studies (AS), Military Science (ML), and Physical Education (PE) courses are not included in any evaluation of Academic Progress.

Academic Progress is evaluated at the end of each semester and any student who does not maintain Satisfactory Academic Progress will move down one level of academic standing (to warning, from warning to probation, or from probation to suspension). First-year students who earn no academic credit (see note above) during their first two terms at WPI will be placed on Academic Suspension. Thereafter, any student who earns no academic credit in a semester will move down two levels in academic standing.

ACADEMIC WARNING

Each student's academic record will be reviewed at the conclusion of terms B and D according to the guidelines above. If a student's performance falls short of either guideline 1 or 2, the student, parent and academic advisor will be notified that the student is not making satisfactory progress. This notification will place the student on Academic Warning for two terms. At this time, the student is urged, with the help of the advisor, to identify the nature of the academic difficulty and to formulate a course of action for overcoming the difficulty. Students on academic warning may apply to the Global Projects Program, but WPI reserves the right to withdraw acceptance to students who are subsequently placed on academic probation.

ACADEMIC PROBATION

During the next review of academic progress, should the student fail, once again, to maintain satisfactory academic progress, the student, parent and academic advisor will be notified. This notification will place the student on Academic Probation for two terms. Academic Probation will prevent the student from receiving financial aid, will result in loss of eligibility for team sports, will prevent the student from obtaining undergraduate employment in the Co-op Program and will prevent participation in the Global Projects Program.

ACADEMIC SUSPENSION

Should a student on Academic Probation fail to make satisfactory academic progress during the next review period, the student will be *suspended* from WPI. The notification will prevent the student from enrolling as a full-time student *or* a part-time student for at least the next two terms. Subsequent readmission is subject to approval (with possible conditions) of a petition through the Registrar to the Committee on Academic Operations (CAO). As a general rule, a student readmitted after suspension will be placed on an Academic Probation status.

New students (first year or transfer) who fail to obtain academic credit for the first two terms shall be placed on Academic Suspension and not allowed to enroll for the following two terms. To apply for readmission, a student must submit a petition to the Committee on Academic Operations (CAO).

IMPROVEMENT IN STATUS

Students on Academic Warning or Academic Probation have the opportunity to improve their status by progressing through the levels in reverse order. If a student on Academic Probation satisfactorily meets the guidelines at the end of the next review period, he or she will be moved to the list of students on Academic Warning. A student on Academic Warning would be moved back to Satisfactory Academic Progress status.

SUMMER REVIEW PERIOD

An exception to the guidelines stated above can occur when a student registers for Term E. At the conclusion of Term E, a review will be conducted which will include E-term and the previous four terms. If the student has completed 10/3 units acceptable work, the student's academic progress status will improve. Thus, a student on Warning status after the Term D review will start terms A and B on Satisfactory Academic Progress. A student placed on Academic Probation after the Term D review will be on Warning status for terms A and B.

SUMMER ACADEMIC SUCCESS PROGRAM

Students who finish the academic year on Academic Warning or Academic Probation status, but who have passed at least 2 units of academic work during the previous four terms, are eligible to participate in the Summer Academic Success Program. Students who participate in the program enroll in ID 1000- Summer Academic Success Program, a five-week academic skills course, as well as two E Term courses. Successful completion of the courses and ID 1000 will result in the academic status rising one level (Academic Probation to Academic Warning, or Academic Warning to Satisfactory Academic Progress). The Office of Academic Advising coordinates the Summer Academic Success Program.

PART-TIME STUDENTS

Students pursuing the bachelor's degree as part-time students will be subject to the same review schedule and standards as full-time students. All part-time students will be reviewed after the Fall and Spring semesters and must satisfactorily complete at least one-third of the academic activities for which he/she has registered. For more information on part-time status, please see page 219.

GRADE CHANGES AND ACADEMIC STATUS

Students who are placed on Academic Warning or Academic Probation at the end of a given semester may receive a grade change (either incomplete to letter or letter to letter) that may improve the standing. The Registrar will re-review a student's standing if the grade change comes in by the last day of the immediately following term. Please note that, depending on the timing of this re-review, the improved standing may not have an effect on financial aid implications. This option is not available to students on suspension. Suspended students must petition the Committee on Academic Operations for reconsideration or to return from suspension.

PETITIONS

Students may petition through the Registrar's Office to the Committee on Academic Operations (CAO) for reconsideration of the status of the following:

- Academic Probation
- Academic Suspension
- Readmission after Suspension

Students who petition for reconsideration of status must accomplish the following:

1. Obtain a petition form from the Registrar's Office webpage.
2. Complete the form and obtain advisor's approval and signature.
3. Submit the form to the Registrar's Office within three weeks of the issuance of grades for B, D, or E term reviews except for readmission after suspension.

DEADLINES FOR READMISSION AFTER SUSPENSION

July 20 for Term A
November 15 for Term C

ADMINISTRATIVE OBLIGATIONS AND HOLDS

The college reserves the right to hold grades, transcripts, registration and/or diploma for any student who has an outstanding administrative obligation with the college.

DIRECTORY INFORMATION AND RELEASE OF INFORMATION

The items listed below are designated as Directory Information and may be released at the discretion of the institution. Under the provisions of the Family Educational Rights and Privacy Act of 1974, as amended, students have the right to withhold the disclosure of any or all of the categories of Directory Information. Written notification to withhold directory information must be received by the Registrar's Office during the first week of the fall semester. Forms are available in the Registrar's Office. A request to withhold directory information in no way restricts internal use of the material by the college.

Directory information will include the student's campus mailbox, full name, year, major, advisor, e-mail address, home address, local address, local phone, photograph, date and place of birth, dates of attendance, degrees and awards received, and most recent or previous educational agency or institution.

Unless a student notifies the Registrar's Office in writing to the contrary, the college considers all undergraduate students to be dependents of their parents. In compliance with the Family Educational Rights and Privacy Act, the college reserves the right to disclose information about the status of dependent students to their parents without the students' written consent. Petition forms for Declaration of Independent Status are available in the Registrar's Office upon request (see information under Distribution of Grades, page 208).

POLICY ON RELEASING INFORMATION ON DECEASED STUDENTS

The education records of deceased students may be released or disclosed, at the time of death, upon written request, to a spouse, a parent, the executor of the estate, the eldest surviving child, the eldest surviving sibling, and surviving descendent, or pursuant to a court order or subpoena. Only the Registrar may release the academic records of deceased students. The person requesting the records must provide as much of the following information as possible within the written request:

Student's name (and maiden name, if applicable).

Student's Social Security number.

Student's date of birth.

The dates that the deceased student attended WPI.

Death Certificate (Photo copy is acceptable).

The petitioner must also provide the following personal information within his/her written request:

Name.

Address.

Phone Number.

Evidence that he/she is qualified to receive the records, based on the above criteria or, in the absence of evidence, a statement certifying the same.

Signature.

Date of request.

REGISTRATION

During the spring, students will receive information regarding course offerings for the following academic year. After consulting with academic advisors, students will make course selections via the online registration system. Students with holds will be prevented from registering until the obligation is met.

A calendar is published by the Registrar's Office prior to the add/drop period which specifies the time periods and fees for late changes. Students are responsible for the dates and should contact the Registrar's Office if they need information to avoid late fees. Requests for exceptions to published deadlines must be submitted in writing to the Registrar's Office and will be granted based on documented extenuating circumstances, i.e., medical, military obligations.

CHECK-IN

At the beginning of terms A and C, students will receive check-in information. Check-in is an on-line confirmation that students will be attending classes or working on a project for that particular semester. In addition, by checking-in, students acknowledge that they will be financially responsible for paying all charges associated with that particular semester. All students must check-in whether or not course changes are to be made.

COURSE CHANGES

There is an add/drop period at the start of each term and the exact deadlines depend on the length of the course session (7, 10, or 14 weeks).

For 7-week courses (undergraduate and graduate), a student can add a course without a fee through the fifth day of classes. On the sixth through the tenth day of classes, students can add courses (with instructor approval) with a $100 late fee. Students can drop courses on days 1-10 of each term without incurring a late fee. For undergraduates in 7-week courses, no adds or drops are allowed after the tenth day of the term. For graduate students in 7-week courses who drop a course after the tenth day, but before the end of the fifth week of the term, a W (Withdrawal) will be assigned. No tuition or fees will be refunded after the tenth day of the term.

For 14-week courses (undergraduate and graduate), students can make course changes (add or drop) without penalty through the tenth day of the semester. A $100 late fee will be charged for course adds after the tenth day of the semester and instructor permission is required. No drops are allowed after the tenth day of the semester; for graduate students, course withdrawals are permitted through the tenth week of the semester, and a grade of W (Withdrawal) will be assigned. No tuition or fees will be refunded after the tenth day of the semester. Consult the University calendar for specific dates.

For 10-week courses (undergraduate and graduate), students can make course changes (add or drop) without penalty through the tenth day of the semester. A $100 late fee will be charged for course adds after the tenth day of the semester and instructor permission is required. No drops are allowed after the tenth day of the semester; for graduate students, course withdrawals are permitted through the seventh week of the semester, and a grade of W (Withdrawal) will be assigned. No tuition or fees will be refunded after the tenth day of the semester.

Note: If a degree-seeking student is dropping or withdrawing from all registered course activity, they must either take an institutional leave of absence or officially withdraw from the University.

WAIT LISTS

When a seat in a class becomes available to a student on the wait list, he or she will be notified via e-mail. The e-mail contains instructions on how to claim the available seat. If a student does not receive an e-mail, it means no seat is available for him/her in the wait-listed class.

OVERLOADS OF COURSES

The standard course load for WPI students is one unit per term (exclusive of courses for ROTC and Physical Education, which do not count towards overloads). Students may register in advance for a maximum of one unit in any term.

Registration for courses which will result in an overload may take place, on a space-available basis, as of the first day of the term in which that course is offered.

A student may not include any portion of qualifying work as part of an overload without the approval of both the academic and project advisors. Written approval will be requested before registration can be completed in such cases.

Overload charges will be computed each semester based on the course and project load based on the student's registration after the add/drop period in the second term of the semester.

Note: undergraduates taking graduate courses receive more credit for said courses and are billed accordingly. Please take this into account when considering overload fees.

To compute overload charges, see Expenses, page 246.

WITHDRAWAL FROM COURSES

Students who wish to withdraw from a course or project will be assigned a grade of NR (No Record) by the instructor. The student should contact the instructor and indicate that he/she will not be continuing in the class.

RECORDS AND AUDITS

TRANSCRIPT FEES

WPI has recently contracted with Credentials Solutions to manage transcript orders. All transcript requests should now be made online and are $5.00 per transcript to be paid by credit card using Credential Solutions.

Please visit https://www.wpi.edu/offices/registrar for more information.

DEGREE AUDITS

WPI has developed a computerized degree evaluation which lists students' courses as they apply to the respective department distribution requirements. The degree evaluation is available online.

GRADUATION

Each student must file an application for degree with the Registrar's Office in accordance with the following schedule:

To graduate in:
May – prior A-term
September – prior D-term
December – prior D-term

PROJECTS

PROJECT PLANNING

During the academic planning period, which starts in February, students who intend to conduct project work during the following year should set aside time to plan their projects, meet with faculty, and form project teams. The faculty will list IQP project opportunities on the Projects Program web page in February. (Some Project Centers and special programs may have an application process before that.) Each academic department typically will list MQPs on the department's web site and will hold a projects information meeting for students in their major. Students are also encouraged to meet with faculty individually.

The most important and difficult part of a project is the planning which precedes the execution. The planning phase of your project will involve developing a background, talking to people in the field, finding out what has already been done in the area, and determining what your goals are and what you need to do to accomplish them. If any special equipment, financing, or resources will be needed for execution of the project, it is especially important to make this known early to ensure that it will be available to you. In addition, most faculty members require a project proposal before registration of the project.

PROJECT REGISTRATION

Students who intend to do project work must complete a project registration form by no later than the beginning of the first term of that project work. The Project Registration Form is available on-line at the Registrar's Office web site, under Forms for Students. Once completed on-line, it must be submitted electronically to the project advisor for approval. Any student who will travel to an off-campus location, such as a Residential Projects Program site, is also required to fill out an electronic project registration form.

Project registration for terms A-E will be accepted up to the 10th day of the term (not including weekends) without penalty. A project involving an off-campus sponsor (MQP mostly, but some IQP) carries the further obligation of compliance with the rules and regulations of the sponsor. Often, these are specified in a formal contract between the sponsor and WPI, and are legally binding. At the time of registration, any affected student will be required to indicate the sponsor on the electronic registration form.

For an MQP, the project advisor or an associate advisor must be a member of the faculty in the discipline which corresponds to the major area of study of the student.

PAY AND CREDIT (for students working on sponsored projects)

A student may receive pay for work associated with a registered project under the following conditions:

1. The work done for pay is clearly distinguished from the work defined for academic credit for the project. This distinction must be clearly articulated in a conflict of interest statement signed by all participating parties before the project begins.
2. Results obtained from paid or unpaid work performed while students are not registered for project credit at WPI may be used in projects only after consultation with the project advisor. When possible, such consultation should take place before work begins.

CHANGE OF REGISTRATION INFORMATION

For all changes in projects, students must use the electronic Project Registration Form. Students may make changes to the project by making an addendum to the previously registered project and submitting the changes electronically to the project advisor for approval.

CHANGING PROJECT ADVISOR

To change the project advisor for a degree-required project, students should stop by the Registrar's Office.

PROJECT CONFERENCES

Students should report to their project advisor's office at the beginning of the term to make arrangements for subsequent meetings.

OVERLOAD WITH PROJECT

Students may not register for an overload (more than 7/3 units per semester) without the electronic approval of the academic advisor.

PROJECT COMPLETION

During the final term of registration for the project and sufficiently prior to the deadline for submittal of Completion of Degree Requirement Forms, students must submit their completed project report to the project advisors. Students are also required to submit a copy of the document to the participating off-campus organization sufficiently prior to the end of the term so that proprietary and confidential information in the report can be identified and removed. Most off-campus organizations require 30 days for this review, and the grade and final report cannot be submitted to the Registrar by the project advisor until this review has been done.

Directions for submitting the project report electronically are available in the Gordon Library or on-line. A final project report is submitted electronically at wpi.edu/+eprojects (See Electronic Project Submission on page 15.)

A completed electronic Completion-of-Degree-Requirement (eCDR) form, must be printed for signature by each student and signed individually by the advisor as the final step in the submission process. The eCDR form must be submitted in person by the project advisor or a member of the academic department of the advisor to the Office of the Registrar by no later than the tenth day of the next academic term.

A student who has filed an application to receive their degree in May must submit a completed eCDR to the Office of the Registrar by the last Thursday in D-term.

REGISTRATION POLICY FOR DEGREE REQUIREMENTS

The completion of a degree requirement (MQP, IQP or Humanities and Arts Requirement) will not be recorded in the Registrar's Office after the tenth day of classes of a term unless the student is registered for a minimum of 1/6 unit *of the same activity* in that term. The deadline for receipt of the Completion Form is no later than the tenth day of classes for the next term. Any exceptions to this policy must be handled by written petition from the project advisor.

Note: Candidates for degrees must meet graduation deadlines if they differ from the above. Deadlines for degree candidates will be strictly enforced!

Only Completion of Degree Requirement (CDR) forms which are complete, correct and consistent with the student's registration records will be accepted by the Registrar's Office. (See PROJECTS AND RESEARCH section, page 14.)

OFF-CAMPUS INSURANCE AND LEGAL AGREEMENTS

WPI's insurance program includes a broad range of coverage for students doing projects in cooperation with off-campus organizations. This insurance coverage requires proper documentation of individual student participation. All students doing project work with off-campus organizations must complete the pertinent portion of the project registration form. In certain cases, where the project is included as part of a regular course, the course instructor must submit to the Projects Office a list of the students going off campus and the name(s) and address(es) of the organization(s) involved.

WPI has entered into a variety of agreements with off-campus organizations, covering a wide range of issues common to the projects program. Students agree to abide by these agreements during the registration for the project.

INDEPENDENT STUDY

Independent Study provides the opportunity for an individual student or group of students, with the approval and under the direction of one or more faculty advisors, to study and to explore in greater depth an area of particular interest to the student and faculty member. An independent study may be used as a substitute for an existing WPI course, as an opportunity to study a topic not currently offered as a course at WPI, or to conduct directed undergraduate research.

Independent Study registration for terms A-E will be accepted up to the 10th day of the term (not including weekends) without penalty.

An independent study may be used to assign credit in a particular discipline only when at least one of the faculty advisors has an appointment in the department or program associated with the discipline or with the approval of the appropriate Department Head or Program Director. If disciplinary credit is not assigned to the independent study, the academic credit will be identified as Interdisciplinary (ID) and the credit will be assigned as free elective on the student's transcript.

OFFICIAL WITHDRAWAL OR LEAVE OF ABSENCE

There are many reasons why a student may need or wish to take time away from WPI. There may be personal or medical issues interfering with their academics; opportunities for professional experience; family or community commitments; or the desire to just take a break.

- Institutional Leave of Absence (LOA): Request this if you are planning to return to WPI. Leaves may be granted for the remainder of the current semester (if applicable) and the immediately following semester (not counting summer). Leaves may be renewed for one additional semester, and an extension must be requested before the expiration date of the current leave. If a student does not return by the expiration date, they will be automatically withdrawn. For students with federal funding in their financial aid awards you will be reported to federal agencies as a federally withdrawn student. This may have impacts on deferment and loan repayment start times. Please contact the Office of Student Aid & Financial Literacy for further details.
- Official Withdrawal: Request this if you are leaving permanently and not planning to return to WPI.

Any reduction in charges is based on the student's certified last date of attendance. See page 246 for information concerning tuition charges.

Students who have attended through the 12th week of a semester (or the 5th week of B or D terms) may not withdraw or take an LOA for that semester and will be academically reviewed. They may withdraw or take an LOA for the following semester.

See Return from Leave of Absence section for information about returning to WPI after a leave. Students who officially withdraw are expected to apply through Undergraduate Admission if they decide they would like to return at a later date to pursue undergraduate study.

See full list below for more information and other types of withdrawals or leaves.

Restrictions to WPI access:

- You will be dropped from any classes and/or projects you have scheduled for future terms.
- You will not be able to live in university housing, and if applicable, will not be able to select or keep your future academic year assignment.
- You may not be able to retain your spot for an IQP/MQP Project Center.
- If you have financial aid, your financial aid will be readjusted.
- You will not be able to participate in campus activities, including clubs, sports, etc.
- Students on Institutional Leave of Absence will retain use of their WPI email. All other access will be removed.
- Students on Official Withdrawal will NOT retain use of their WPI email. All other access will also be removed.

Procedure:

1. Students should inform themselves about the consequences to the following if applicable
   - Financial Aid
   - Visa Status
   - Housing
   - Billing, including potential tuition adjustments
   - Health insurance: If insured by student health insurance please check for coverage options.
   - Undergraduate students schedule an appointment with Academic Advising

   And any other considerations.
2. Complete the appropriate form available at https://www.wpi.edu/offices/registrar
   - Undergraduate Institutional Leave of Absence Form
   - Undergraduate Official Withdrawal Form

3. If seeking a medical leave of absence, please make an appointment with the appropriate office below
   - If seeking a medical leave of absence for psychological reasons, schedule an appointment with the Student Development and Counseling Center (SDCC).
   - If seeking a medical leave of absence for all other medical reasons, schedule an appointment with WPI's Office of Health Services.
4. Submit completed form to Registrar's Office

RETURN FROM LEAVE OF ABSENCE

Students who have been away from WPI for a voluntary institutional leave of absence or medical leave of absence may request to return from leave of absence. The return from leave of absence process has been designed to make sure that students are ready to return successfully to **WPI. Students must submit a request to return before the leave of absence expires. If the leave expires you will be automatically withdrawn.**

All students requesting to return to WPI must complete the Request to Return from Leave of Absence Form and submit it to the Registrar's Office by the applicable deadlines. Please note that students returning from a medical LOA must be cleared by the appropriate office. Forms and information are available at https://www.wpi.edu/offices/registrar.

Deadlines: Fall Semester: July 20th
Spring Semester: December 1st
Summer Session: May 1st

PART-TIME DEGREE STUDENTS

Students may apply for Part-Time Student status on a **semester** basis at the Registrar's Office. Part-time students pay tuition on the basis of registered credit at the start of each semester, including credits for ROTC and PE. Campus housing will not be allowed. Part-time students may not engage in varsity/club sports, may not participate in any extracurricular activities, and are only eligible to apply for limited federal and state financial aid (institutional financial aid is not available) including any form of on-campus student employment. The following registration procedures apply:

- Students who wish to enroll as part-time students must apply by July 20 for the Fall semester and by November 15 for the Spring semester. Such status will allow a maximum of one unit per each semester of the academic year.
- Changing between full-time/part-time status is not allowed at mid-semester.
- Part-time students wishing to return as full-time students must be readmitted according to the procedures specified under Readmission in the Admissions section of this catalog, page 242.

For the Guidelines for Determination of Satisfactory Progress for Part-time Students, see page 214.

NON-DEGREE STUDENTS

Students wishing to take courses on a full-time or part-time basis as a non-degree student may do so by contacting the Registrar's Office. Non-degree students are permitted to earn a maximum of 18 credits (6/3rds) in a non-degree status. Non-degree students will be tracked through the Registrar's Office. Non-degree students pay tuition on the basis of registered credit at the start of each semester. Campus housing will not be allowed. Non-degree students may not engage in varsity/club sports, may not participate in any extracurricular activities, may be required to register for courses on a space-available basis, and *are not eligible for financial aid or any form of on-campus student employment.*

PROJECT REGISTRATION TOPIC CODES

MQP MAJORS AND COORDINATORS

	Majors	Coordinators
AE	Aerospace Engineering	N. Gatsonis
BIO	Biology and Biotechnology	J. Rulfs
BBC	Biology and Biotechnology with Concentration	J. Rulfs
BC	Biochemistry	D. Heilman
BU	Business	A. Hall-Phillips
BME	Biomedical Engineering	G. Pins
CE	Civil Engineering	T. El-Korchi
CH	Chemistry	D. Heilman
CHE	Chemical Engineering	W. Clark
CS	Computer Science	C. Wills
ECS	Economics/Science	O. Pavlov
ECE	Electrical and Computer Engineering	J. McNeill
EVS	Environmental and Sustainability Studies	L. Elgert
EV	Environmental Engineering	J. Bergendahl
HU	Humanities	D. Spanegel
ID	Interdisciplinary	R.Vaz
IE	Industrial Engineering	S. Johnson
IMG	Interactive Media & Game Development	J. deWinter
INGS	International and Global Studies	P. Hansen
MA	Mathematical Sciences	J. Petrucelli
MAC	Actuarial Mathematics	J. Abraham
ME	Mechanical Engineering	B. Savilonis
MFE	Manufacturing Engineering	K. Rong
MGE	Management Engineering	A. Hall-Phillips
MIS	Management Information Systems	E. Loiacono
PH	Physics	D. T. Petkie
PHE	Applied Physics	D. T. Petkie
RBE	Robotics Engineering	C. Pinciroli
STP	Society, Technology & Policy	P. Stapleton
PW	Professional Writing	E. Boucher
PSS	Psychological Science	J. Skorinko

HUMANITIES AND ARTS ADVISORS

Topics	Project Advisor
Topics in American Studies	J. Aguilar, K. Boudreau, S. Bullock, C. Clark, J. Cocola, J. Cullon, L. Davis, H. Droessler, B. Eddy, J. Hanlan, L. Schachterle, D. Spanagel
Topics in Asian Studies	J. deWinter, W. Du, J. Rudolph, H. Zheng
Topics in Art	R. Bigonah, F. Chery, A. Gonzalez, E. Gutierrez, M. Keller, J. Rosenstock, M.D. Samson,
Topics in Drama/Theatre	K. Moncrief, D. Giapoudzi
Topics in Environmental Studies	C. Clark, J. Cocola, J. Cullon, R. Gottlieb, J. Sanbonmatsu, W. San Martin, D. Spanagel
Topics in European Studies	U. Brisson, D. DiMassa, P. Hansen, J. McWeeny, S. Nikitina
Topics in Gender Studies	L. Davis, M. Ephraim, J. McWeeny, R. Moody
Topics in Global Studies	D. DiMassa, H. Droessler, J. Galante, P. Hansen, S. Lessing, A. Madan, R. Moody, G. Pfeifer, A. Rivera, J. Rudolph, W. San Martin, Y. Telliel
Topics in History (American)	S. Bullock, J. Cullon, L. Davis, H. Droessler, J. Hanlan
Topics in History (Global)	H. Droessler, J. Galante, P. Hansen, J. Rudolph, W. San Martin
Topics in History (Science and Technology)	C. Clark, J. Cullon, W. San Martin, D. Spanagel
Topics in Intercultural and Global Competency - Humanities (Interrelated)	E. Boucher, U. Brisson, A. Danielski, J. deWinter, D. DiMassa, H. Droessler, W. Du, M. El Hamzaoui, J. Galante, P. Hansen, S. Lessing, A. Madan, J. McWeeney, R. Moody, S. Nikitina, G. Pfeifer, A. Rivera, J. Rudolph, W. San Martin, Y. Telliel, H. Zheng
Topics in Latin American Studies	J. Galante, A. Madan, A. Rivera, W. San Martin
Topics in Literature (American)	J. Aguilar, K. Boudreau, J. Cocola, J. Harmon, K. McIntyre, S. Nikitina, L. Schachterle
Topics in Literature (Contemporary)	J. Aguilar, K. Boudreau, J. Cocola, M. Ephraim, K. McIntyre, K. Moncrief, S. Nikitina, L. Schachterle
Topics in Literature (Global)	J. Aguilar, K. Boudreau, J.Brattin, J Cocola, D. DiMassa, M. Ephraim, A. Madan, K. Moncrief, S. Nikitina, A. Rivera
Topics in Medical Humanities	B. Eddy, B. Faber, S. Lessing, L. Higgins
Topics in Middle East and African Studies.	M. Brahimi, M. El Hamzaoui, R. Moody, Y. Telliel
Topics in Modern Languages (Arabic)	M. Brahimi, M. El Hamzaoui
Topics in Modern Languages (Chinese)	W. Du, H. Zheng
Topics in Modern Languages (German)	U. Brisson, D. DiMassa
Topics in Modern Languages (Other)	A. Rivera
Topics in Modern Languages (Spanish)	A. Madan, A. Rivera
Topics in Music	S. Barton, F. Bianchi, V.J. Manzo, J. Rohde, D. Weeks
Topics in Philosophy	R. Gottlieb, J. McWeeney, G. Pfeifer, J. Sanbonmatsu
Topics in Religion	B. Eddy, R. Moody, Y. Telliel
Topics in Urban Studies	J. Cullon, B. Eddy, J. Hanlan, D. Spanagel
Topics in Writing (Creative)	J. Aguilar, J. Cocola, M. Ephraim, J. Harmon, K. McIntyre
Topics in Writing (Professional)	E. Boucher, J. deWinter, B. Faber, J. Harmon, L. Higgins, S. Lessing, K. Lewis, R. Madan, S. Nikitina, Y. Telliel
International Students	E. Boucher, A. Danielski, M. El Hamzaoui
IMGD	F. Chery, J. deWinter, A. Gonzalez, E. Gutierrez D. O'Donnell, J. Rosenstock

RESOURCES AND SPECIAL PROGRAMS

SECTION 5

Resources and Special Programs . . . 222
The Gateway Park . . . 222
Special Programs for First Year Students . . . 222
Graduate Courses . . . 222
Combined Bachelor/Master's Program . . . 222
Information Technology Services . . . 223
Music and Theatre Facilities . . . 224
George C. Gordon Library . . . 225
Student Services . . . 226
Student Exchanges . . . 227
Language Requirements . . . 227
HECCMA Course Cross-Registration . . . 228
Cooperative Education . . . 228
Summer Session (Term E) . . . 230
Awards and Prizes . . . 231
Societies, Registration and Licensing . . . 234

THE GATEWAY PARK

In 2010, WPI added Gateway Park — a growing center of research, innovation, and commerce — to the campus footprint. It began as a joint venture with the Worcester Business Development Corporation to transform a blighted and underutilized area in into a clean, thriving, mixed-use facility for a range of academic, research, and commercial enterprises. Today Gateway Park includes facilities located at 50 Prescott Street (Gateway II), 60 Prescott Street (Gateway I), and 85 Prescott Street that house a number of academic and research programs, such as Robotics Engineering, the Biomanufacturing Education and Training Center (BETC), an expanded state-of-the-art Fire Protection Engineering research and burn laboratory, the Foisie Business School, and the Life Sciences and Bioengineering Center. Gateway Park is also home to a number of WPI administrative offices and two commercial enterprises.

SPECIAL PROGRAMS FOR FIRST YEAR STUDENTS

INSIGHT PROGRAM

In WPI's Insight Program, groups of 25-30 first year students are advised by a faculty mentor who makes a real commitment to these students during the first two terms. Each faculty advisor works with two upper class students, a Community Advisor and a Resident Advisor. Together they plan and run a number of activities for the first year students, frequently on the residence hall floor. Examples of these activities include workshops on time management, study skills, or test-taking strategies, as well as social events such as laser tag, pizza parties and apple picking. The Insight program purposefully blends the academic and social aspects of life at WPI, helping students form a strong support network.

GREAT PROBLEMS SEMINARS

This is a two course sequence designed to serve as an introduction to project work and university level research with a focus on themes of global importance. Each seminar has at its core an important problem. Students explore the complexity of our global issues, and demonstrate their ability to solve some aspect of the big problem. The skills the students develop are exactly what they need to be successful both in project work at WPI and in their future careers.

Examples: In Food Sustainability, students and faculty focus on issues surrounding food: nutrition, production, economics, and policy issues. Student projects have included plans for urban gardens, extending Meals on Wheels to younger but non-mobile seniors and nutritional information in the dining hall.

In the Power the World, the production, distribution and use of all forms of energy and associated ethical issues are reviewed. Student projects have included stove design for indigenous people, improvements on solar powered emergency medical devices and energy audits of campus buildings.

Themes will change from year to year. Enrollment is limited.

DISCOVERING MAJORS AND CAREERS

Discovering Majors and Careers is a class for first year students undecided about academic majors. This 1/12 unit course can be taken on top of a regular course load. Students enrolled in this course will utilize a variety of tools including self-assessments, panels, campus resources, and informational interviews with alumni to help identify personal interests, WPI majors, related careers, and life goals. The program has a terrific track record in choosing majors that align with interests and skills.

ADDITIONAL RESOURCES ON THE WEB

The Undergraduate Programs Web Site (www.wpi.edu/Academics/Undergraduate/)

The Academic Advising Office (www.wpi.edu/+OAA)

The First Year Web Site (www.wpi.edu/+FYE)

GRADUATE COURSES

WPI students may enroll in graduate courses as part of their regular undergraduate studies without being admitted to the graduate program. An exception: In order to enroll in graduate courses offered by the Robert A. Foisie School of Business, the student must have been admitted to a dual BS/MS program, regardless of department. Graduate courses applied toward the undergraduate degree are awarded undergraduate units with a conversion rate of 1 graduate credit = 1/6 undergraduate unit.

COMBINED BACHELOR/ MASTER'S PROGRAM

INTRODUCTION

WPI undergraduates can begin work on a graduate degree by enrolling in a combined Bachelor's/Master's program. This accelerated course of study allows students to obtain an MS degree after only five years of full-time work (i.e., typically one year after completion of the BS). Students often obtain the BS and MS in the same field or department, but with careful planning some students complete the combined BS/MS program in two different fields; the combination of a BS in Civil Engineering and an MS in Fire Protection Engineering is a common example. (Throughout this section, "MS" will be used to refer to all Master's-level degrees; most students who complete the combined program obtain the MS).

PLANNING YOUR PROGRAM

Because BS/MS students use some approved courses to satisfy the requirements of both degrees simultaneously, it is crucial for them to plan their curriculum early in their undergraduate career.

The specific course and MQP requirements for a BS/MS program are determined individually, so students should consult with their own advisor as well as the graduate coordinator in the department in which they plan to pursue their MS degree early in their Junior year. This consultation, or series of consultations, should produce a slate of approved undergraduate courses that will be used for graduate credit. Sometimes the instructors of these courses will ask BS/MS students to complete additional work, or will otherwise hold them to higher standards of achievement.

A student's advisor and graduate coordinator will also determine what role the MQP will play in the BS/MS program. Sometimes the MQP provides a foundation for a thesis. In cases where the BS and MS are not awarded in the same field, the MQP usually relates to the graduate program's discipline.

Once the specific course and MQP requirements have been established, students complete a Course Selection Form which is submitted to the relevant department(s) for approval. This written agreement constitutes the set of conditions that must be met for a student to complete the BS/MS program. They are a plan for completing the requirements for both degrees and they will not supersede or otherwise obviate departmental and university-wide requirements for either degree. The completed, signed form must be submitted to the Registrar before the student may matriculate in the combined program.

HOW TO APPLY

Students almost always apply for admission to the BS/MS program in their Junior year, typically after they have established their curriculum and other program requirements and completed the Course Selection Form with their faculty advisors. Applications are submitted to the Office of Graduate Admissions and are processed with all other graduate applications. Once a decision has been reached, the Office of Graduate Admissions will notify the student, usually within six weeks of completing the application.

PROGRAM REQUIREMENTS

Only registered WPI undergraduates may apply for admission to the combined BS/MS programs. Students are considered undergraduates, no matter what courses they have completed, until they have met all of the requirements for the Bachelor's degree. In order to receive the BS and the MS, all of the requirements for both degrees must be completed.

In most departments a student may take up to four years to complete the Master's portion of the BS/MS program. There are exceptions, however, so students are advised to discuss their timetable with the appropriate advisor or graduate coordinator. Students who stop registering for classes for an extended length of time may be asked to petition the Committee for Graduate Studies and Research to continue their program.

CREDIT EQUIVALENCE AND DISTRIBUTION

No more than 40% of the credit hours required for the Master's degree, and which otherwise meet the requirements for each degree, may be used to satisfy the requirements for both degrees. In some departments, students may not double-count more than 30% of their graduate credits. Consult the graduate catalog for the requirements of your program.

Double-counted courses are recorded on the transcript using the credit hours/units and grades appropriate at the graduate or undergraduate levels. For students in the combined BS/MS program, approved undergraduate courses are assigned graduate credit with a conversion rate of 1/3 WPI undergraduate unit = 2 graduate credit hours, while graduate courses applied toward the undergraduate degree are awarded undergraduate units with a conversion rate of 1 graduate credit hour = 1/6 undergraduate unit.

INFORMATION TECHNOLOGY SERVICES

WPI Information Technology Services offers a wide range of information technology resources to the WPI community to support teaching, learning, research and student life.

ACCESS

The WPI computer account acts as an undergraduate student's WPI virtual identity while the student is actively registered. Usage is governed by the Acceptable Use Policy. The account provides access to many technology resources including:

Network:

- Wired and wireless network available in all academic buildings, residence halls, and participating Greek houses
- High speed Internet connectivity including connection to Internet2
- Virtual Private Network (VPN) provides secure remote access to WPI on-campus information technology resources
- Information Security monitors the WPI network and provides data malware protection

University Systems:

- University services, such as email, learning management system, eProjects, web site, software applications, remote desktop, databases, etc. are enabled by System Operations and Web Development teams.
- Enterprise-wide technology solutions such as Banner, Workday, and their related data systems, enable administrative departments to run the critical business functions of the University. They provide students and faculty access to student registration, advising, and financial information. They also enable students to update their biographical information, set proxy, and check grades online.

Software

Students can access numerous software applications including academic courseware:

- in public computer labs
- via remote services
- via network download for some applications
- discounted purchase via online store

COMPUTER LABS

Over 700 public computers are available across campus for student use. Many are located in open access labs within academic buildings and throughout the Gordon Library. Public computer labs offer a consistent user interface and software profile. Speciality labs for students include:

- Multimedia Lab enabling high-end digital editing is available in the Gordon Library
- Maker space, prototyping and recording labs are housed in the Foisie Innovation Studio
- Design Studio offers powerful workstations for CAD/FEA/FEM projects and coursework in Higgins Labs

PRINTING SERVICES

The Gordon Library Information Commons Print Center is available to meet students' scanning and printing needs. Printers are also located throughout the Gordon Library as well as within some computer labs. For additional printing services listed below see Technology Support and Instruction:

- Large-format poster printing
- Rapid prototyping/3D printing

COLLABORATION AND LEARNING RESOURCES

Collaboration and learning are supported through specialized software and applications, technology-enhanced spaces, and equipment loans.

- Learning Management Software: Canvas course web sites
- Tools: Office 365 (email/calendar/contact, task, document management), Digication portfolio, FusionForge, Skype for Business
- Web-conferencing: Zoom allows remote participants to conduct meetings in real-time in a web-based environment from any location with a web-enabled device and a high speed Internet connection
- Tech Suites: Technology-enhanced meeting spaces with wireless screensharing designed for student project group use
- Learning Spaces: Active learning classrooms, electronic classrooms, and electronically enabled conference rooms
- Equipment Loans: Laptops, digital cameras, audio recorders, hard drives, projectors, etc.

TECHNOLOGY SUPPORT AND INSTRUCTION

Technology Service Desk

Gordon Library, Main Floor; (508) 831-5888; its@wpi.edu; https://its.wpi.edu

- In-person technology support provided at the Service Desk
- Requests for assistance can be submitted via phone, email or web
- IT Service, Software, and Knowledge Catalog provides answers to common issues

Academic Technology Center

Fuller Labs, Room 117; (508) 831-5220; atc@wpi.edu

- In-person technology support on audio-visual equipment loaned out for multi-media projects and campus events sponsored by WPI student organizations
- Large-format poster printing

Academic and Research Computing

Higgins Labs, https://www.wpi.edu/research/resources/support/academic-research-computing

- Instructor-led scientific and engineering software applications training
- Data management and access to cloud collaboration space
- Numerous high performance computational resources available for student research projects
- Large-format poster printing located in Higgins Labs
- Enterprise level rapid prototyping/3D printing located in Higgins Labs

MUSIC AND THEATRE FACILITIES

COMPUTER MUSIC LABORATORIES

Alden Memorial and Sanford Riley Hall

These laboratories support creative and research activity in a variety of music- and sound-related applications including real-time virtual orchestra design and production techniques. The lab contains hardware and software for multi-track digital recording and editing, signal processing, algorithmic composition, sound synthesis, MIDI sequencing, music notation, and music programming. The computer music classroom is located in the basement of Alden Hall.

FIRST BAPTIST CHURCH

The Choral Department is housed in the First Baptist Church, located on the north corner of WPI's campus. Each of the four choirs (Glee Club, Alden Voices, Festival Chorus, and Chamber Choir) hold their weekly rehearsals at the church, along with many a cappella groups. The ensembles regularly rehearse in the spacious and versatile Gordon Hall, while giving three performances a year in the resonant sanctuary. The office for the Director of Choral Activities and choral library are also located within the church.

GREAT HALL OF ALDEN

Alden Memorial: First Floor

The Great Hall is used for major productions in Music and Theatre. It is the venue for the VOX Musical Theatre performances as well as choral and instrumental performances. In addition, the Hall is sometimes used for festive and gala campus functions.

ALDEN HALL THEATRE SPACES

Alden Memorial: First Floor

Alden Hall houses many of the performance activities at WPI, both academic and extra-curricular. The Green Room serves as a space for rehearsals, meetings and other academic projects of the theatre community. The sub-basement of Alden Hall houses a scenic design studio and a Props & Costumes closet. These areas are maintained and shared by the Department of Humanities and Arts Drama/Theatre division and Masque, the WPI undergraduate student theatre club..

JAZZ HISTORY DATABASE LAB

The Jazz History Database lab, located in the basement of Alden Hall, is an interactive multimedia museum focused on artists deserving of wider recognition and dedicated to the preservation of "at-risk" jazz artifacts. The rare and unique materials on this website have been contributed by individuals, academics, institutions and media from the U.S. and Internationally. The Jazz History Database is hosted by Worcester Polytechnic Institute (WPI) under the direction of Professor Richard Falco, Director of Jazz Studies. Academic credit is awarded to students working in teams to preserve materials for archiving and inclusion in the database.

THE LITTLE THEATRE

Sanford-Riley, Lower Level

Made possible with a major gift from the George I. Alden Trust, the Little Theatre is the University's first dedicated academic theatre facility. With a combination of flexible and fixed seating, this 99-111 seat facility has a permanent lighting grid and sound system, a high-tech control booth, a greenroom/dressing room, and handicapped accessibility. The Little Theatre is well suited for a wide range of theatrical performances and is the laboratory for the Drama/Theatre division of the Department of Humanities and Arts. Audiences appreciate the intimate relationship they have with the production and the Little Theatre often sells out each show. Undergraduates who work in the Little Theatre may earn academic credit in theatre classes and projects; other students take part in activities in the Little Theatre as part of Masque or Alpha Psi Omega; and many others participate simply for the enjoyment of taking part in a live play onstage. For more information, see http://users.wpi.edu/~theatre.

MUSIC, PERCEPTION AND ROBOTICS LAB

Alden Memorial: B21

The Music, Perception and Robotics Lab explores how creative expression can be inspired by and enhanced through technological tools and understanding of human auditory perception. The lab designs, builds, composes for and performs with musical robots. It conducts psychological research that examines human musical perception and creativity. It synthesizes these efforts by developing software that allows human musicians to interact with robotic ones.

SPAULDING RECITAL HALL AND OTHER ROOMS FOR REHEARSAL AND PERFORMANCE

Alden Memorial: Lower Level

Alden Center for the Performing Arts houses the Spaulding Recital Hall, Perreault Chamber Rehearsal Room, the Janet Earle Choral Rehearsal Room, three practice rooms, and the Knight Lecture Room. Available for practice are Steinway grand pianos and the Three Manual Aeolian-Skinner pipe organ in the main Concert Hall. There are three concert grand pianos for recitals, ensemble work and concerts. WPI has some instruments that can be made available to students upon request.

OTHER MUSIC FACILITIES

Music facilities also include The Janet Earle Room, The Perreault Chamber Rehearsal Room, the music classroom, practice rooms, computer music labs and storage facilities.

DRAMA/THEATRE RESOURCE LIBRARY

The Department of Humanities and Arts Drama/Theatre Resource Library, housed in Salisbury Labs Room 18 and available as posted, contains publications, magazines, published scripts, and other information to assist students working on projects (MQP, IQP, practica, ISU) in Drama/Theatre. Scripts for current productions can usually be found nearby the Resource Library on the table in the center of the main Humanities and Arts area. Most resource items and display scripts must be used in the immediate area, and this service is not per se a lending library.

GEORGE C. GORDON LIBRARY

The George C. Gordon Library welcomes more than 400,000 visitors each year, and provides resources and innovative services that support teaching, learning, scholarship, and community at WPI. Gordon Library Information Services, the ITS Service Desk, and the Technology for Teaching and Learning (TTL) group of the Academic Technology Center (ATC) are conveniently co-located near the library's main entrance on the second floor. The adjacent Class of 1970 Library Café serves food and beverages. Students may access the library from 8am to 1am Monday-Thursday, with special weekend hours and extended hours to 3am during finals.

The library's four floors contain a wide variety of individual and group study spaces. Tech Suites are private collaborative work rooms equipped with large monitors and wireless screen-sharing technology, and can be reserved for student use. Additional group study spaces are located throughout the building. Among them is Studio@Gordon, an active and informal collaboration space on the ground floor.

The library offers both wireless and wired computer network access throughout the library's open study areas, with over 125 computers that offer free access to dozens of high quality software packages. The Multimedia Lab on the first floor offers specialized multimedia software and hardware, and a public KIC Click Mini book scanner for quick and easy scanning of books and other materials. The adjacent Shuster Lab for Digital Scholarship offers 6 high-end workstations equipped with digital scholarship and multimedia software and Huion 20" graphics tablet monitors; large monitors for wireless screen sharing and presentations; two high-end scanners; and a docucam. It is available for student use whenever not scheduled by faculty or staff for special class use or events.

The staff of Gordon Library offers many services to support student learning. Research and instruction librarians help students with research problems and questions, offer library instruction and orientation sessions, and provide research consultations to individuals and project groups.

The library's information resources support the curriculum and research needs of the WPI community. The library offers an extensive collection of print and electronic books and journals, as well as more than 250 research databases, all selected to support WPI courses, projects, and scholarship. The library also provides access to books by WPI faculty authors, recreational reading, music, videos, and video games.

The library catalog, electronic journal and book collections, specialized research databases, course-specific information, and many other resources are available from the library's web site (wpi.edu/library) which features powerful search options and links to research guides, journals, articles, databases, and other digital resources and services. Access to WPI users who are off-campus is available through an institutional login.

Through the Digital WPI platform (digital.wpi.edu), the library collects and offers global digital access to WPI student work including GPS posters, IQP and MQP reports, graduate theses and dissertations, as well as selected WPI faculty research.

All students can request materials not held in Gordon Library through a free interlibrary loan service. WPI students also have access to the collections of other academic libraries within Central Massachusetts through the library's membership in the Academic and Research Collaborative (ARC). Students can obtain an ARC cross-borrowing card which allows direct borrowing at many regional academic libraries.

The Archives and Special Collections, located on the ground floor, serves as the institutional memory of WPI and curates the university's collection of manuscripts, rare books, photographs, art, and objects. Its staff works with the campus community to access historical resources related to WPI, Industrial Revolutions, and regional history. Highlights from the collection include university history, the Morgan Construction Company records, and a world-class collection of material related to the life, world, and works of Charles Dickens. These items can be explored through ArchivesSpace (archives.wpi.edu), and are available to researchers by visiting the Fellman Dickens Reading Room, with select digitized and digital-born material hosted at Digital WPI (digital.wpi.edu).

Special exhibits are offered in the library's galleries. WPI authors are regularly invited to talk about their work in the library's Meet the Author series, and other programming occurs regularly to serve the WPI community.

For more information, please visit the library website at wpi.edu/library.

STUDENT SERVICES

STUDENT DEVELOPMENT AND COUNSELING CENTER

The Student Development & Counseling Center (SDCC) is dedicated to promoting the safety, emotional health, and personal growth of all WPI students, as well as to cultivating a supportive campus.

The SDCC offers free, confidential mental health counseling and consultation services for individuals, couples, and groups, as well as crisis intervention and referrals to local specialists as necessary. Without exception, each student will be treated with compassion and respect, and counselors will work with them to set goals, identify obstacles, and move in a valued direction.

Additionally, the SDCC hosts trainings, workshops, and presentations that are designed to foster personal growth and skills for success.

Students interested in learning more about the SDCC and its services are encouraged to email us at sdcc@wpi.edu, call us at 508-831-5540, or visit us during our operating hours. The main office is located at #16 Einhorn Road. We are open Monday-Thursday from 8:00 am-7:00 pm and Friday from 8:00 am-5:00 pm, with walk-in hours from 2:00 pm-3:00 pm each day while students are in session. Our summer hours are 8:00 am-4:30 pm.

ACADEMIC RESOURCES CENTER

WPI's Academic Resources Center (ARC), located in Daniels Hall, provides academic support services that are designed to enrich and enhance the learning experience of all WPI undergraduate students. Its student-based collaborative learning environment offers individualized assistance in a variety of subjects, as well as a comprehensive peer tutoring program.

The ARC offers individual and group tutoring (MASH) sessions. All peer tutors and MASH Leaders are certified by the College Reading and Learning Association, and help students in a variety of academic subjects. Peer tutors are available by appointment, whereas MASH sessions are drop-in. To schedule an appointment with a peer tutor visit tutortrac.wpi.edu. To view the MASH schedule visit: www.wpi.edu/+OAA.

MASH (MATH AND SCIENCE HELP) PROGRAM

MASH is an academic support program for students in mathematics, science, and computer science courses. Offered to all students enrolled in a supported course, MASH provides assistance in regularly scheduled study sessions beginning the first week of the term.

Each group tutoring session is guided by a MASH leader, an undergraduate student who has taken the course before and who, therefore, understands the course material and what the instructor expects. MASH leaders attend lectures, and conduct three 50-minute MASH sessions each week. By attending class and demonstrating effective student behavior, MASH leaders can assist students with the language of the discipline, the integration of lecture and readings, and the development of good study habits.

Through the MASH program, students become actively involved with the content material in a supportive environment. MASH participants master new concepts, learn to put ideas into perspective, and develop a better way to study.

OFFICE OF DISABILITY SERVICES

The Office of Disability Services (ODS) coordinates accommodations and provides support for WPI students with documented disabilities to equally participate in programs and campus life. The office strives to foster an environment that supports and encourages self-advocacy, independence, and personal growth. Accommodations can be provided to students with disabilities that are permanent in nature as well as temporary injuries for short-term accommodation support. More information on how to disclose a disability, supports available through the Office, or general questions can be found on our webpage at: www.wpi.edu/+disabilities.

Our services are confidential and available to any student enrolled in a WPI course, though disclosure to the Office is voluntary. Students seeking accommodations or services are responsible for identifying themselves to the ODS as well as providing documentation of their disability by a licensed professional.

ODS is located in Daniels Hall, Room 124.We are open Monday-Friday 8am to 5pm with walk-in hours available A-D terms from 2 to 3pm. Please call the office at 508-831- 4908, or email disabilityservices@wpi.edu, or stop into Daniels 124 to schedule an appointment.

THE WRITING CENTER

The WRITING CENTER, located on the second floor of Salisbury Labs (SL 233), employs ~20 peer writing tutors trained to help undergraduate and graduate students with any type of communication project: course papers and project reports, application documents, dissertations, oral presentations and slides, website and document design, and more. Through one-on-one appointments, tutors talk through project goals, help writers brainstorm and organize ideas, provide a critical reader's feedback, and provide mini-reviews of grammar and punctuation rules. To make an appointment, visit our website at www.wpi.edu/+writing. Faculty interested in designated tutoring for courses should contact Writing Center Director, Ryan Madan, at x6561 or ryanmadan@wpi.edu

WRITING COURSES AND ADVISORS

For information on WPI's writing programs, see Humanities and Arts faculty as follows:

Students interested in the Professional Writing major or the Writing and Rhetoric minor should contact Esther Boucher-Yip (SL 109) about these programs.

The HUA advisors for undergraduate international students whose native language is not English are Esther Boucher-Yip and Althea Danielski (SL 105).

STUDENT EXCHANGES

As technology and commerce become increasingly international in outlook, students in engineering, science and business must learn about countries and cultures other than their own. To respond to this need, WPI offers its students an extensive range of opportunities to broaden their academic and cultural perspectives through participation in the Global Projects Program. WPI also offers traditional exchange programs.

The principal academic emphasis in all exchanges is upon course work. In such programs, students must work closely with their advisor, the academic advisor of the exchange program, and the program coordinator at the site to design an individual program of study. Students have the responsibility of obtaining prior tentative approval from their department that courses taken abroad will count towards departmental distribution requirements. For final transfer credit evaluation, students must provide upon return the necessary detailed information on the content of courses taken abroad and the satisfactory completion of all work. In some exchanges, opportunities exist to complete project work (IQP, MQP, and Humanities and Arts requirement). The exchanges offer exceptional possibilities for projects comparing American and overseas applications of technology and the impact of technology on society. For WPI students on these exchanges, time is usually available for additional travel, before or after the formal academic period.

For more information on these programs, consult with Leanne Johnson in the Interdisciplinary and Global Studies Division or the academic advisor listed for each program.

LANGUAGE REQUIREMENTS

The usual language of instruction at most of the exchange institutions is the official language of the host country. While these institutions may offer a few courses taught in English, most lectures will be given in a foreign language. Thus, exchange students who intend to complete substantial course work must acquire the necessary language background. In some cases intensive language instruction can be arranged on site. In other cases, students acquire the language background through courses taught at WPI or other colleges, or by self-study. A few exceptions exist at some technical universities where the official language of instruction may be English.

UNIVERSITY OF APPLIED SCIENCES; KONSTANZ, GERMANY; EXCHANGE

Students who already know German or are planning to begin studying it have the opportunity to study in Germany for a semester at the Hochschule für Technik, Wirtschaft und Gestaltung (HTWG: university of applied sciences; http://www.htwg-konstanz.de/) in Konstanz, Germany. The city of Konstanz, located at the western end of Lake Constance (in German, der Bodensee) and right on the border with Switzerland, is one of Germany's most beautiful cities, with a well- preserved medieval and renaissance city center. The snow- covered Alps are visible across the lake and the HTWG campus is on the bank of the Rhine where it flows out of the lake and heads north. The city is pedestrian friendly, has great food, and there are unlimited opportunities for biking, boating, swimming, skiing, and hiking in the immediate vicinity. Weekend travel to Austria, Italy, and France is easy and Switzerland is literally right across the street. Students who begin their study of German in Terms A, B, C can complete the Humanities and Arts requirement by attending the HTWG in Terms D and E. WPI will not charge these students extra tuition for Term E. Students whose German is already at an intermediate or advanced level may take either advanced language courses or technical courses at the HTWG. Admission to this exchange program is competitive.

NEOMA BUSINESS SCHOOL, REIMS & ROUEN, FRANCE; EXCHANGE

Perfect opportunity for any Foisie Business School major or minor to spend a fall or spring semester in France, immersing yourself in French culture while studying at NEOMA Business School. NEOMA is one of the top ten business schools in France and ranked as one of the best business schools in Europe by the Financial Times. Courses at NEOMA are taught in English and French.

Students may study in either Reims or Rouen, France. Reims, a historic city in the Champagne Region, has a rich legacy, offering a prestigious home to one of the most celebrated and festive of wines – champagne! Thanks to the high-speed train (TGV), Reims is only 45 minutes from Paris and 30 minutes from Roissy-Charles de Gaulle airport. Rouen is located on the River Seine with a beautiful medieval city center. Rouen was fashioned by history, and has seen the likes of Joan of Arc, William the Conqueror and Claude Monet walk its streets. Dynamic festivals and events bring present day Rouen to life. The campus in Rouen offers students beautiful surroundings in seven hectares of woodland and is equipped with state-of-the-art equipment. It is located less than two hours from Paris and the coast of Normandy.

Students participating in this exchange program pay regular WPI tuition, but pay semester room and board to NEOMA. FBS staff will help students map out a curriculum at NEOMA, ensuring all NEOMA credits will transfer back into WPI. Admission to this exchange program is competitive.

HECCMA COURSE CROSS-REGISTRATION

The Higher Education Consortium of Central Massachusetts (HECCMA) consists of the following institutions: Anna Maria College, Assumption College, Becker College, Clark University, College of the Holy Cross, Cummings School of Veterinary Medicine at Tufts University, Massachusetts College of Pharmacy and Health Sciences, Quinsigamond Community College, University of Massachusetts Medical School, WPI and Worcester State University. Full-time WPI students who cross-register for courses at other HECCMA colleges pay no extra fees. Students are limited to one course per semester. The no-charge plan does not include evening colleges or summer school. For cross registration information visit www.heccma.org.

Students interested in registering for HECCMA courses should discuss their program with their advisors, and then obtain regulations and registration forms from the Registrar's Office.

COOPERATIVE EDUCATION

CO-OP

The WPI Cooperative Education Program (known as Co-op) provides an opportunity for students to alternate time in the classroom with extended periods of paid, full-time, career-related work experience in industry or government agencies. The program, which is optional at WPI, entails work assignments during the summer or during the academic year. The following are the options of duration for undergraduate students:

1. Summer and A term
2. Summer, A term and B term
3. C term, D term and Summer
4. D term and Summer
5. Summer, A term, B term, C term and D term
6. A term, B term, C term, D term and summer

Most students elect to participate in one Co-op assignment, though students may choose to complete up to two. Students who participate in the Co-op program can graduate on time especially when they have Advanced Placement coursework and/or have planned ahead. It is recommended that students pre-plan during their first or second year at school. Preparation of a complete four year plan with the student's academic advisor is required to ensure compatible scheduling of work periods and academic courses.

In order to qualify for the Co-op program, students must meet the following requirements:

1. Must be a current, full time, undergraduate WPI student in good standing. Note: If any of the following conditions apply a student may petition for eligibility.
   a. Not in good academic standing (i.e. on academic warning or probation)
   b. Have financial holds on their account
   c. Have a judicial record. Note: having a judicial record does not automatically preclude you from participating in a Co-op.
   d. Want to register for up to 1/3 unit of course while on Co-op.
2. International students must complete one full academic year at WPI before being eligible for Co-op, due to US Federal Government regulations. In addition, the Co-op must be related to the major (not minor). For questions, please contact International House.
3. Understand the impact Co-op would have on your federal and institutional financial aid through a meeting with the Office of Student Aid & Financial Literacy.
4. Understand the impact your Co-op will have on your course schedule and outline your four year plan, including projects, Co-op, etc. and have it reviewed through a required meeting with your Faculty Advisor.
5. Approval will be needed from your Faculty Advisor, Office of Student Aid & Financial Literacy, Supervisor at your Co-op, Bursar, Dean of Students Office, Career Development Center (CDC), and International House (if applicable). Approvals are done electronically through Handshake, beginning with you entering your Co-op information in your Handshake Account's Experiences section. The deadline for fall Co-ops is August 1; the deadline for spring Co-ops is December 1. Co-ops received after deadline are reviewed on a case by case basis. Submissions after the add/ drop deadline will not be approved.
6. To be considered, the Co-op must be full time (at least 30 hours per week), paid, 4-8 months in duration and related to your major and career goals.
7. Understands and accepts the Terms of Agreement. (see website for more info at wpi.edu/+coop)

ADVANTAGES TO STUDENTS AND EMPLOYERS

Co-op offers several advantages to students:

1. Students gain experience, build their resume and bring theory into practice.
2. Co-op earnings enable students to pay a significant portion of their college expenses.
3. Sharpen skills and abilities as an emerging professional.
4. Test out career options to help clarify career goals and interests.
5. Return to school with new knowledge and experience in their field.
6. Position themselves for future opportunities; Co-op participants are preferred full time hires.
7. Transcript will show Co-op and indicate company name.

Co-op also offers several benefits to employers:

1. Co-op students can handle assignments that may be difficult for untrained personnel, but that do not require the talents of experienced professionals
2. The program gives employers the chance to judge the actual on-the-job performance of potential permanent employees.
3. Retention rates for permanent employees recruited though a Co-op program are higher than for those hired through other routes.

THE CO-OP PROCESS

Students interested in participating in Co-op should contact the Career Development Center to set up a Co-op information appointment. The following is a list of things that need to be done prior to the CDC processing a Co-op application:

1. Meet with your faculty advisor and the Office of Academic Advising to develop an academic plan including Co-op and your degree requirements.
2. Students with financial aid must schedule a meeting with the Office of Student Aid & Financial Literacy to discuss a Co-op's impact on your financial aid status.
3. Meet with the Career Development Center to learn how to search and apply for Co-ops. This includes resume and cover letter writing, job search strategies and resources, interview skills, and salary negotiation. The Career Development Center encourages you to use appointments, drop ins or attend workshops to prepare. If you would like to learn more about Co-op please schedule a Co-op Information appointment.
4. Please read the Terms of Agreement (visit wpi.edu/+coop for information). When submitting the Undergraduate Co-op Forms you are confirming you have read, understand and will abide by the terms.
5. Remain registered for courses until your Co-op is processed. The Office of the Registrar will then un-enroll you from courses and register you for Co-op.
6. Apply, interview, and accept a Co-op position and utilize the CDC for support. After officially accepting an offer, you should immediately withdraw applications with any other companies. Politely let them know you have accepted another position so other students may benefit. The CDC can help you with communicating this; if you need assistance or would like to role-play the scenario please make an appointment with a CDC Staff Member or visit the CDC during drop-in hours. Employers will appreciate your professionalism.
7. Complete the Undergraduate Co-op Program Forms which are found in your Handshake account. To begin, enter your Co-op in the Experiences section, which will then include your acknowledgement to abide by the Terms of Agreement, allow review of your Judicial Record through the Dean of Students Office, Bursar for financial holds, approval by your Faculty Advisor that you have communicated your four year academic course plan, the Co-op experience, and that you are in good academic standing, supervisor at the company, the Office of Student Aid & Financial Literacy, Career Development Center, International House (if applicable), and for you to upload a copy of the job description, and an offer letter mentioning start date, end date, salary and supervisor contact information. Should you be submitting a petition, you will submit this while filling out the aforementioned forms.
8. The CDC will initially confirm that your Co-op meets the Eligibility Requirements of the Undergraduate Co-op Program. After the CDC's initial confirmation on your Co-op, the approval process begins. Once all approvals are received and granted, notification will be sent to the Registrar, the Office of Student Aid & Financial Literacy, the Bursars Office, and if applicable, International House and Residential Services, as well as to you and your faculty advisor and supervisor. The Registrar at this point will un-enroll you from academic courses in the terms you will be away and register you for CP 100_ (the applicable courses that align with your time on Co-op).
9. Make arrangements for your housing in the new location/ Sublet your current off-campus apartment/Return your residence hall key before traveling to your Co-op. If you do not make arrangements for your current housing or return your residence hall key to Residential Services you will be charged for housing.
10. You may now start your Co-op on the date agreed upon with your employer. Enjoy your experience, and know the Career Development Center is here to support you through this experience.

Employers seeking to fill a Co-op position provide the CDC with a job description on Handshake, our web-based system. Students will then apply to those positions through Handshake by forwarding their resume and cover letter to the appropriate companies. In addition, students can look for Co-op experiences on their own initiative. Some employers interview candidates on campus; others review resumes and then invite selected students for on-site interviews. The final hiring decision is left to the employer. The student is free to interview with more than one employer and to identify opportunities outside of WPI's postings, ultimately choosing among the employment offers received. Once a decision is made, students are required to stop interviewing and applying for other positions and alert pending employers that they are no longer looking.

INFORMATION AND REGISTRATION

Students interested in exploring the possibility of participating in the program should contact:

Career Development Center
Project Center, Lower Level
(508) 831-5260
coop@wpi.edu
www.wpi.edu/+coop

SUMMER SESSION (TERM E)

With course offerings directed at meeting student needs, a variety of sessions, and both traditional and blended classes, E-term provides flexibility for students looking to work over the summer and still take advantage of these academic opportunities. E-term is a great time to

- Get back into good academic standing
- Lighten the load for the next year
- Speed up your time to degree completion
- Stay on track in the BS/MS program

E-term offers an exceptional opportunity to participate in certain types of project activity on a convenient basis since classrooms and laboratories will be less crowded and outside field work will enjoy better weather conditions. E-term also offers an excellent opportunity to complete a qualifying project through a full-time effort during a single term.

Since class sizes are generally smaller in E-term, students will enjoy more individually-oriented course work – a real benefit for classes that students find challenging or courses that are designed to prepare students for more advanced classes in their major.

Students planning to participate in Term E should register at the regular spring registration period. For more information, including payment and financial aid information, visit the E-term webpage at: https://www.wpi.edu/academics/undergraduate/summer-courses

Students from other campuses are also invited to take advantage of E-term offerings at WPI. Admission to the summer session does not imply admission to regular academic year programs. Students desiring to continue their work at WPI following the summer session should seek admission following standard WPI admissions procedures issued through the Admissions Office.

EARLY RESEARCH EXPERIENCE IN E TERM (EREE)

The Early Research Experience in E Term (EREE) program is designed to provide early research experience to interested students who have not yet had an authentic research experience. We will provide current first and second-year students an initial immersive research experience with a WPI faculty mentor. The goal of this program is to create pathways to deep and meaningful research experiences in STEM fields for undergraduate students, especially those from traditionally underrepresented groups in STEM including underrepresented minorities, first-generation students, transfer students, and women.

Students apply to participate in this research program and are selected and matched to an appropriate research opportunity. They work full time as part of a research team in the summer. All EREE students attend weekly professional development workshops, and share their research at a summer undergraduate research celebration at the end of the program.

Awards and prizes are determined by the academic department or by selected committees.

COLLEGE AWARDS

SALISBURY PRIZE AWARDS

These historic awards are made to highly meritorious seniors. These awards were established by Stephen Salisbury, a WPI founder and former president of the Board of Trustees.

TWO TOWERS PRIZE

This prize is awarded to the student who, through general academic competence, campus leadership, regular course work and special work in research and projects, best exemplifies a combined proficiency in the theoretical and practical union implicit in the Two Towers concept, which is at the heart of WPI's Two Towers tradition.

SIGMA XI AWARDS IN ENGINEERING AND SCIENCE

These awards in engineering and science are given to the students and their advisors for the Major Qualifying Projects which are judged to be the best in originality, contribution to the field, professional competence, and for the most useful applications.

PRESIDENT'S IQP AWARDS

These awards are given to student teams whose conception, performance, and presentation of their Interactive Qualifying Projects have been judged outstanding in focusing on the relationships among science, technology, and the needs of society.

PROVOST'S MQP AWARDS

These awards offer recognition to those students who have completed outstanding Major Qualifying Projects as a demonstration of their competency in a chosen academic discipline. Each academic department conducts its own competition to select the winners.

CLASS OF 1879 AWARD

Endowed by the Class of 1879, this prize is awarded by the Humanities and Arts Department yearly for excellent work in the culminating project for the Humanities and Arts Requirement. Projects must demonstrate exceptional creativity and skill in conceiving, developing, and expressing a theme within any discipline within the humanities and arts.

UNITED TECHNOLOGIES CORPORATION MINORITY AWARD

This award is presented to an outstanding minority undergraduate student.

OUTSTANDING WOMEN STUDENT AWARDS

Marietta E. Anderson Award, an award which is presented to the most outstanding woman student in one of the three lower classes who not only has a superior academic record, but also has been a work-study student, participated in recognized extracurricular activities, and has been a volunteer for college-sponsored activities.

Funds from an anonymous donor provide the following awards to women students preparing for careers in engineering or science. Awards are based on academic excellence, contributions to the WPI community, and professional goals. The awards are named each year for women who have played significant roles at WPI.

Bonnie-Blanche Schoonover Award, honoring WPI's former librarian.

Ellen Knott Award, honoring a long-time secretary in the Mechanical Engineering Department.

Gertrude R. Rugg Award, honoring WPI's late Registrar Emerita.

WILMER L. AND MARGARET M. KRANICH PRIZE

Students who are seniors or completing their junior year will be nominated by faculty for the annual award. The award will go to a student majoring in engineering, science or business who best exemplifies excellence in the humanities and in the full integration of humanities into his/her undergraduate experience. Double-majors who fulfill one major in Humanities and Arts are not eligible.

CHARLES O. THOMPSON SCHOLARS

Named in honor of the first president of WPI, this honor recognizes outstanding performance by first-year students.

To be eligible for membership, students must receive all A's and B's, with a minimum of six A's, in their academic subjects during the first three terms at WPI. Selections are made in Term D.

A cash award is presented to the outstanding first year student. Charles O. Thompson Scholars are eligible to apply for this award by submitting an essay to the Office of Undergraduate Studies during D Term.

SPECIAL AWARDS

ALPHA PHI OMEGA SERVICE AWARD

AMERICAN INSTITUTE OF CHEMISTS FOUNDATION

Chemistry and Biochemistry

An award by the New England chapter of the American Institute of Chemists to honor outstanding seniors majoring in chemistry and biochemistry.

AMERICAN SOCIETY FOR METALS: CHESTER M. INMAN '14 OUTSTANDING STUDENT AWARD

Mechanical Engineering

The Worcester Chapter of the American Society for Metals presents $200 to a student for excellence in a Major Qualifying Project dealing with processing or materials science.

HAROLD S. BLACK AWARD

Electrical and Computer Engineering

This award was established in 2001 to honor the memory of inventor Harold S. Black '21. The award is given by the faculty of the Electrical and Computer Engineering (ECE) Department to one or more ECE seniors who have demonstrated outstanding creativity and enthusiasm in engineering problem solving, practical implementation of problem solutions, and exemplary character in their contributions to the welfare of the WPI community.

CENTRAL NEW ENGLAND AICHE AWARD FOR SIGNIFICANT CONTRIBUTION
Chemical Engineering
This award is given to an individual in recognition of significant contributions to the American Institute of Chemical Engineers.

COMMUNITY SERVICE AWARD PRESENTED IN THE MEMORY OF EDWIN B. COGHLIN '23
Alumni Office
This award recognizes individuals who have demonstrated an extraordinary personal commitment above and beyond their normal involvement on campus in both academic and extracurricular activities.

COMPUTER SCIENCE OUTSTANDING JUNIOR AWARD
Computer Science
This award is presented to a computer science junior who has an excellent academic record and who shows promise for continuing success.

COMPUTER SCIENCE OUTSTANDING SENIOR AWARD
Computer Science
This award is presented to one or more computer science seniors who have an outstanding record and who have contributed to the enrichment and professional development of fellow students.

JAMES F. DANIELLI AWARD
Biology and Biotechnology
This award, given by the Department of Biology & Biotechnology, honors the memory of Dr. James F. Danielli, a former department head and world-famous scholar.

FRANK D. DEFALCO AWARD
Civil and Environmental Engineering
Award to WPI undergraduate Civil Engineering students who has completed two and one half years towards a B.S., interested in career constructed facilities and a member of ASCE student chapter.

ETA KAPPA NU OUTSTANDING STUDENT AWARD
Electrical and Computer Engineering
The electrical and computer engineering honor society presents this award to the outstanding senior and junior in recognition of their academic achievement and their service to the WPI community.

GENERAL CHEMISTRY ACHIEVEMENT AWARD
Chemistry and Biochemistry
This award is given to the student who has completed the freshman chemistry course with superior academic performance. Department award.

ALLAN GLAZER AWARD
Mechanical Engineering
Established in 1992 by the family and friends of Allan Glazer '47, this award is given to a junior majoring in mechanical engineering who has demonstrated outstanding academic achievement, special ingenuity in problem solving, and enthusiasm for engineering challenges.

GOAT'S HEAD AWARD
Student Government Association
Awarded annually to the outstanding new Senator of the year.

THE ROBERT H. GODDARD AWARD
Physics
Established by the classes of 1908 and 1909 as a memorial to Dr. Goddard, this prize is awarded for outstanding achievement, scholarship, consistent effort and dedication of purpose in both theoretical and experimental areas of physics.

HEALD BROTHERS SCHOLARSHIP
Mechanical Engineering
This scholarship identifies and supports outstanding young men and women who represent, in modern form, the spirit of "Yankee Ingenuity" that characterizes the evolution of the great manufacturing enterprises from the beginnings of the American Industrial Revolution.

ANDREW HOLT MEMORIAL AWARD
Civil and Environmental Engineering
This award is presented to a civil engineering senior who has consistently earned academic honors and who shows excellent promise for success.

STEVEN J. KAHN AWARD
Humanities and Arts
This award is presented to the outstanding senior in the WPI Glee Club in recognition of his contribution, commitment, and unwavering loyalty to the organization.

THE WILLARD ELLIOT LAWTON-SAMUEL JAMES PLIMPTON AWARD
Physics
Established in honor of Professors Lawton and Plimpton, this award is presented to a student who has shown improvement in scholarship, not only in grades but also in depth of understanding.

LINCOLN ARC WELDING FOUNDATION AWARD
Civil and Environmental Engineering
This award recognizes outstanding achievement in solving design, engineering, fabrication, and research problems.

MEDWIN HONORS STRING QUARTET SCHOLARSHIP
Humanities and Arts
Scholarship money is given to the members of the Medwin Honors string Quartet (4 string players, 2 violins, 1 viola, 1 cellist), who are selected by audition each year.

THE ALFRED R. AND JANET H. POTVIN AWARD
Biomedical Engineering
Separate awards are given to the outstanding undergraduate and graduate student in Biomedical Engineering in recognition of their academic performance and their service to WPI and/or the outside community.

CARL F. MEYER IMPROVEMENT AWARD IN CIVIL ENGINEERING
Civil and Environmental Engineering
Established by Professor Emeritus Meyer, this award is presented to the civil engineering senior who has demonstrated the most improvement in academic and professional attitude since entering the department.

RICHARD V. OLSON AWARD
Mathematical Sciences
Established to honor the memory of mathematics Professor Richard V. Olson, this annual award to a WPI sophomore recognizes outstanding performance in basic mathematics courses.

EDWARD C. PERRY AWARD
Mechanical Engineering
This award is given annually to an engineering student or students for an outstanding major qualifying project in the area of mechanical design. The award is made possible through a bequest from Miriam Perry Goll and honors the memory of her father, Edward C. Perry '04, a design engineer with General Electric Company throughout his professional career.

PI TAU SIGMA AWARD FOR EXCELLENCE
Mechanical Engineering
The mechanical engineering honor society, Pi Tau Sigma, presents this award to the outstanding junior mechanical engineering student.

ROBOTICS ENGINEERING OUTSTANDING JUNIOR AWARD
Robotics Engineering
This award is presented to a robotics engineering junior who has an excellent academic record and who shows promise for continuing success.

ROBOTICS ENGINEERING OUTSTANDING SENIOR AWARD
Robotics Engineering
This award is presented to one or more robotics engineering seniors who have an outstanding record and who have contributed to the enrichment and professional development of fellow students.

SENIOR MATHEMATICAL SCIENCES MAJOR AWARD
Mathematical Sciences
This award is presented to the senior mathematical sciences major who has shown outstanding performance and who has made valuable contributions to the WPI mathematical community.

SOCIETY OF MANUFACTURING ENGINEERING SCHOLARS AWARD
Mechanical Engineering
An SME Student Chapter member, recommended by the faculty and confirmed by the officers of SME chapter 25, who has demonstrated excellent scholarship, leadership, service, potential to contribute to the profession of Manufacturing Engineering.

The award includes scholarship assistance ($900) for full-time study if the winner enrolls in WPI's graduate MFE program.

SOCIETY OF MANUFACTURING ENGINEERING UNDERGRADUATE SCHOLARSHIP AWARD
Mechanical Engineering
Awarded to a 1st, 2nd, or 3rd year SME Student Chapter member, recommended by the faculty and confirmed by the officers of SME chapter 25, who has demonstrated excellent scholarship and commitment.

SOCIETY OF MANUFACTURING ENGINEERS OUTSTANDING STUDENT AWARD
Mechanical Engineering
Awarded to the top three SME Student Chapter members each year, regardless of year, who have not already received the award.

SOCIETY OF MANUFACTURING ENGINEERS MQP AWARD
Mechanical Engineering
An SME Student Chapter member, selected by a panel of practicing manufacturing engineers to have the best MQP in the area of Manufacturing Engineering.

STUDENT-ALUMNI INTERACTION AWARD
Alumni Office
This award is presented by the WPI Alumni Association in recognition of individuals who, through their involvement on campus, have facilitated the continuing development of interaction between students and alumni. Recipients are full-time undergraduate students who have demonstrated extraordinary personal commitment to WPI and the Alumni Association above and beyond the normal involvement on campus.

The award is designed to recognize students who have stepped forward to become leaders in the alumni and student communities and, in doing so, have benefited both WPI students and alumni in a unique and purposeful way.

ACS UNDERGRADUATE AWARD IN ANALYTICAL CHEMISTRY
Chemistry and Biochemistry
Award which is intended to encourage student interest in analytical chemistry and to recognize a student who displays an aptitude for a career in the field. This award is for third-year students.

ENGINEERING SOCIETIES

All engineers are professionals in accordance with the definition of engineering, one of which states that "engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind." Professional engineers also observe a code of ethics, exercise judgment and discretion while providing their services, and are involved in a confidential relationship with their clients. Professional engineers enjoy legal status, use professional titles, and associate together through professional societies.

An excellent way to begin learning about the status of the professional engineer is to join the student branch of a professional society relevant to your interests. At WPI, students are encouraged to join the student branches of such societies as the American Society for Metals (ASM), American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronic Engineers (IEEE), the American Society of Civil Engineers (ASCE), the American Institute of Chemical Engineers (AIChE), the American Institute of Aeronautics and Astronautics (AIAA), the Association of Computing Machinery (ACM), the American Nuclear Society (ANS), APICS, the Institute of Industrial Engineers (IIE), the Society of Automotive Engineers (SAE), the Society of Manufacturing Engineers (SME), the Society of Fire Protection Engineers (SFPE), the Society of Women Engineers (SWE), the American Chemical Society, (ACS), and the Society of Hispanic Professional Engineers (SHPE). For information on these organizations, see the appropriate department head.

ENGINEERING REGISTRATION AND LICENSING

In order to become a "Professional Engineer" (P.E.) and enjoy the legal status which affords certain rights, privileges and responsibilities, engineers must qualify through the formal procedures of registration and licensing. Procedures vary from state to state, but in most cases, the applicant must pass a Fundamentals of Engineering Examination.

FUNDAMENTALS OF ENGINEERING EXAMINATION

To become legally registered as a professional engineer (P.E.), candidates must submit data regarding formal education and technical ability to the appropriate state Board of Registration for Professional Engineers. Two major examinations, The Fundamentals of Engineering Examination (also called Engineering-in-Training, E.I.T.) and the Professional Practice Examination (P.P.E.), must be successfully completed as a measure of technical ability. The Fundamentals Examination must be taken first; the Professional Practice Examination must then be taken after a designated period of substantial professional experience, usually a minimum of four years. File applications for E.I.T. by January 1. The E.I.T. Examination will be given in mid-April and late-October. File applications for Professional Practice Examinations (P.P.E.) six months in advance.

There are several possible qualification paths to registration as a P.E. The quickest and most common route is to obtain a degree from an ABET (Accreditation Board for Engineering and Technology-formerly ECPD) accredited curriculum, and to acquire the specified amount of suitable professional level experience in addition to passing the two examinations mentioned above. There are seven ABET accredited curricula at WPI-biomedical engineering, civil engineering, chemical engineering, electrical and computer engineering, industrial engineering, manufacturing engineering, and mechanical engineering. Persons with an unaccredited degree can still become registered in most, but not all, states by submitting evidence of a longer "apprenticeship" period (variable by states) before taking the two examinations. Students should strive, if at all possible, to pursue a program which is accredited by ABET and should work closely with their advisors and appropriate major departments to assure that the total program qualifies for accreditation, since this will greatly facilitate the achievement of registration in the future.

ALL SENIOR ENGINEERING MAJORS IN BME, CE, CHE, ECE, AND ME ARE URGED TO TAKE THE FUNDAMENTALS OF ENGINEERING EXAMINATION WHICH IS GIVEN ON CAMPUS EACH FALL AND SPRING. There will never be a better time!

Refresher courses for students, alumni and practicing engineers are available. Successful completion of this examination is normally the first step in eventually obtaining the right to use the initials "P.E."

WPI's Office of Continuing Education sponsors an eleven session EIT Refresher course from mid-January through mid-April on the WPI Campus. The course, which is taught by WPI faculty, includes reviews of the major topics covered on the exam. For further information, call 508-831-5517.

DESCRIPTION OF FUNDAMENTALS OF ENGINEERING EXAMINATION (F.E.E.)

Typical Date Given: Last Saturday in October (also in April).

Typical Application Deadline: First week in September (also in January).

Duration: Eight hours.

Type: Multiple choice, open book.

CAREER DEVELOPMENT AND GRADUATE SCHOOL

Career Development and Graduate School Advising 236
Career Development Center 236
Graduate Study at WPI 237

SECTION 6

CAREER DEVELOPMENT AND GRADUATE SCHOOL ADVISING

CAREER DEVELOPMENT CENTER

The Career Development Center (CDC) at WPI serves all degree seeking undergraduate and graduate students in the development of life-long skills related to careers, the internship/co-op and job search process, and the pursuit of graduate studies. The CDC serves all undergraduate and graduate students in addition to offering free lifetime alumni services.

The Career Development Center (CDC) provides a variety of services to students including the following:

1. INDIVIDUAL APPOINTMENTS – Students can easily schedule one-on-one appointments with a CDC Staff Member online through their Handshake account in order to get help on a wide variety of topics. Students can choose to discuss topics ranging from major selection, exploring career options, searching for internships/co-ops/jobs, interviewing, applying to graduate school, and evaluating and negotiating job offers.
2. DROP-IN HOURS – Students can also be seen by a CDC Staff Member during advertised drop-in hours. During these times, an appointment is not required and students can get help on a first-come, first-served basis with their resume/cv, cover letter, interviewing skills, job offer evaluation and negotiation, and other quick 15 minute questions.
3. HANDSHAKE – All students are provided with an account for the CDC's web-based system called Handshake. Handshake contains internship, co-op, part-time, and full-time job opportunities posted by employers for WPI students. Handshake also contains a company directory and information about upcoming events and career fairs hosted by the CDC. In addition, Handshake's resources section has special subscription resources (free of charge) that the CDC provides for students.
4. SUBSCRIPTION RESOURCES – The CDC maintains a subscription to several resources to assist students in their career development and job search process, which are housed in Handshake. Among the many resources the CDC offers to students are: MyPlan (self-assessments, majors and careers database, graduate school search), CareerShift (internship/job, company, and contacts search), Going-Global (country/state-specific career resources and H-1B visa company database, interviewstream (interview practice and feedback), Vault (Career, Industry and company exploration) and Versatile PhD (Industry career options for PhDs). These are free for students to use.
5. CAREER OUTLOOK PAGES – The CDC has put together a webpage with short descriptions of what can be expected from different WPI majors and careers, including average salaries, companies that have hired WPI graduates in a particular field, sample job titles, professional associations and clubs, popular industries, and more.
6. CAREER FAIRS – Each year the CDC organizes career fairs for students to network with employers and obtain information on full-time, summer internship and co-op opportunities. The CDC hosts 2 in person events and many more events virtually.
7. CAREER WORKSHOPS – Throughout the year, the CDC delivers frequent workshops for students on a wide variety of career development topics. Common workshop topics include: resumes/cover letters, internship/co-op/job search strategies, networking, interview skills, job offers and negotiation, and applying to graduate school, among others.
8. NETWORKING NIGHTS and CAREER EXPOS – The CDC hosts networking nights and career expos throughout the year to give students an opportunity to network with alumni, fellow students, and industry professionals.
9. COMPANY INFORMATION SESSIONS – Companies host events on-campus to present on their organization, culture, and technology while networking and sharing opportunities with students. Check your WPI Handshake account for upcoming events.
10. JOB OPPORTUNITIES – Job Postings are presented to WPI students and alumni exclusively by employers who want to hire WPI talent within the CDC Handshake system. Review and apply to Cooperative Education, Internships and Job positions to develop work experience.
11. ON-CAMPUS INTERVIEWS – Each year over 1,000 interviews are held on campus with a variety of private, non-profit, and government organizations. Employers interview students for full-time, summer internship, and co-op opportunities. For a list of companies actively seeking candidates for interviews, please utilize your Handshake account
12. RESUME DATABASE – Students and recent alumni may elect to make their resume viewable to employers through Handshake. If available, employers can access your "public" resume and may result in an interview request leading to a future opportunity.
13. GRADUATE STUDIES – The Career Development Center (CDC) and the graduate coordinators in each department can help students search for graduate programs at WPI (BS/MS, MS, MEng, PhD) or elsewhere and assist with preparing for and applying to graduate school.
14. ALUMNI ASSISTANCE – WPI alumni have free lifetime access to the CDC's services, whether they are seeking new employment or making a career change.

LOCATION: The Career Development Center is located in the lower level of the Project Center. The CDC can be contacted by phone at 508-831-5260 or by email at cdc@wpi.edu. The website is www.wpi.edu/+CDC

INTRODUCTION
WPI offers more than fifty graduate degree programs that enable students to deepen and enrich their understanding of a field, and to develop their professional expertise.

GRADUATE PROGRAMS

Aerospace Engineering
- Master of Science in Aerospace Engineering
- Ph.D. in Aerospace Engineering

Bioinformatics and Computational Biology
- Master of Science in Bioinformatics and Computational Biology
- Ph.D. in Bioinformaticis and Computational Biology

Biology and Biotechnology*
- Master of Science in Biology/Biotechnology
- Master of Science in Biotechnology
- Ph.D. in Biology and Biotechnology

Biomedical Engineering*
- Master of Science in Biomedical Engineering
- Master of Engineering in Biomedical Engineering
- Ph.D. in Biomedical Engineering

Business
- Master of Business Administration (M.B.A.)
- Master of Science in Information Technology
- Master of Science in Innovation with User Experience
- Master of Science in Management
- Master of Science in Marketing and Innovation
- Master of Science in Operations Analytics and Management
- Master of Science in Supply Chain Management
- Ph.D. in Business Administration
- Graduate Certificate

Chemical Engineering
- Master of Science in Chemical Engineering
- Professional Master of Science in Chemical Engineering
- Ph.D. in Chemical Engineering

Chemistry and Biochemistry
- Master of Science in Chemistry
- Master of Science in Biochemistry
- Ph.D. in Chemistry
- Ph.D. in Biochemistry

Civil and Environmental Engineering
- Master of Science in Civil Engineering
- Master of Science in Environmental Engineering
- Interdisciplinary Master of Science in Construction Project Management
- Master of Engineering in Civil Engineering
- Ph.D. in Civil Engineering
- Graduate Certificate
- Advanced Certificate

Computer Science
- Master of Science in Computer Science
- Master of Science in Computer Science Specializing in Computer Security
- Ph.D. in Computer Science
- Graduate Certificate
- Advanced Certificate

Data Science
- Master of Science in Data Science
- Graduate Certificate
- Ph.D. in Data Science

Electrical and Computer Engineering
- Master of Science in Electrical and Computer Engineering
- Master of Engineering in Electrical and Computer Engineering
- Master of Engineering in Power Systems Engineering
- Ph.D. in Electrical and Computer Engineering
- Graduate Certificate
- Advanced Certificate

Fire Protection Engineering
- Master of Science in Fire Protection Engineering
- Ph.D. in Fire Protection Engineering
- Graduate Certificate
- Advanced Certificate

Interactive Media & Game Development
- Master of Science in Interactive Media & Game Development

Interdisciplinary Programs
- Master of Science in:
  - Power Systems Management
  - System Dynamics and Innovation Management
  - Systems Modeling
- Ph.D., Interdisciplinary Studies
- Graduate Certificate in Nuclear Science and Engineering
- Graduate Certificate in System Dynamics and Innovation Management

Learning Sciences and Technologies
- Master of Science in Learning Sciences and Technologies
- Ph.D. in Learning Sciences and Technologies

Manufacturing Engineering
- Master of Science in Manufacturing Engineering
- Ph.D. in Manufacturing Engineering
- Graduate Certificate

Materials Process Engineering
- Master of Science in Materials Process Engineering

Materials Science and Engineering
- Master of Science in Materials Science and Engineering
- Ph.D. in Materials Science and Engineering

Mathematical Sciences
- Master of Mathematics for Educators (M.M.E.)
- Master of Science in Applied Mathematics
- Master of Science in Applied Statistics
- Professional Master of Science in Financial Mathematics
- Professional Master of Science in Industrial Mathematics
- Ph.D. in Mathematical Sciences
- Ph.D. in Statistics

Mechanical Engineering
- Master of Science in Mechanical Engineering
- Ph.D. in Mechanical Engineering
- Graduate Certificate in Mechanical Engineering for Technical Leaders

Physics
- Master of Science in Physics
- Ph.D. in Physics

Robotics Engineering
- Master of Science in Robotics Engineering
- Ph.D. in Robotics Engineering
- Graduate Certificate

STEM for Educators
- Master of Science in Mathematics for Educators (MMED)
- Master of Science in Physics for Educators (MPED)

Social Science and Policy Studies
- Master of Science in System Dynamics
- Ph.D. in System Dynamicss
- Graduate Certificate in System Dynamics

Systems Engineering
- Master of Science in Systems Engineering
- Ph.D. in Systems Engineering
- Graduate Certificate
- Advanced Certificate

* *Fall semester admission only.*

At WPI, the Master of Engineering degree is rooted in practice; its aim is to cultivate advanced professional and technical competence. It does not require a thesis and is most appropriate for students who plan to pursue careers in industry.

The Master of Science has a stronger theoretical component than the Master of Engineering degree. Its aim is to prepare students for careers in research and development or academia. The M.S. is the more natural precursor to the Ph.D., although students with an M.Eng. can also successfully obtain this credential. WPI offers both thesis-based and non-thesis Master of Science degrees.

The Ph.D. indicates that a student has undertaken original research and has demonstrated mastery of his or her field through the completion of a substantial project. Ph.D. students present their research findings in a dissertation that is subject to review by the faculty and, in some cases, by professional peers outside of WPI.

WPI's M.B.A. program leverages the University's technical and scientific strengths, focusing on the integration of business and technology. Some key areas of study include: technology commercialization; data quality; health systems innovation; leading change; and user experience.

Finally, the Professional Master of Science and the Master of Mathematics for Educators degrees are akin to the Master of Engineering degree in that they are practice-oriented in both conception and scope.

Further information and the specific requirements for these advanced degrees may be found in the Graduate Catalog (http://www.wpi.edu/+gradcat).

ADMISSION

Prospective graduate students are encouraged to discuss their academic plans with the graduate coordinator of their desired program.

Students may take graduate courses without being formally admitted to a degree program; that is, as a non-matriculating student. But each department limits the number of courses a non-matriculating student may count towards a degree. In some programs, a student may complete as many as four courses without being admitted. No department permits a student to complete more than four courses before a formal admission decision has been made. If you plan to enroll in classes as a non-matriculating student, be sure to contact your department to learn what restrictions have been placed on course work completed before admission to a degree program.

Students should contact the Office of Graduate Admissions (grad@wpi.edu) if they have questions about their application or the application process. In general, each department requires its applicants to submit a completed application, original transcripts of all previous academic work, and three letters of recommendation. The Graduate Record Examination (GRE) is required in some programs and strongly recommended in others. Be sure to check the website for your program to learn its application requirements.

Once a student's application is complete, the Office of Graduate Admissions sends it to the department for review. When the faculty have reached a decision, the Office of Graduate Admissions will notify the student with a formal letter. Decisions are usually rendered four to six weeks after the application has been completed.

Applications for graduate study are accepted year-round. WPI alumni and current WPI undergraduate students are exempt from the $70 application fee.

REGISTRATION AND TUITION PAYMENT

Registration for graduate courses begins several months before the beginning of each semester. Students are encouraged to register for their courses as early as possible.

Tuition for courses taken by graduate students is $1,513 per credit hour for the 2018-2019 academic year. Undergraduate courses listed as "one-third unit" are equivalent to two graduate credit hours.

Tuition and fees, including health insurance, must be paid by the due date on the electronic bill (eBill) or at the time of registration.

COMBINED BS/MS PROGRAMS

For information on combined BS/MS programs, see page 222.

FINANCIAL AID

INTRODUCTION

Prospective graduate students who wish to be considered for WPI assistantships and fellowships are strongly advised to submit their applications by January 1st for Fall admission and October 1st for Spring admission. Assistantships and fellowships typically include full or partial remission of tuition and a monthly stipend. Only full-time graduate students are considered for assistantships and fellowships and preference is given to students who are actively conducting research. Students indicate that they want to be considered for funding on their graduate application forms. There is no separate application for assistantship or fellowship support at WPI.

ASSISTANTSHIPS

There are two types of assistantships at WPI. Teaching assistants support the faculty in the grading of papers, the supervision of laboratory sections, and other teaching duties. Research assistants, on the other hand, are usually given some facet of a larger sponsored-research project that typically becomes a part of the student's thesis or dissertation. Fellowship assignments are made by the faculty in each department and are approved by the Office of the Provost.

NSF GRADUATE RESEARCH FELLOWSHIPS

The National Science Foundation awards multi-year fellowships to promising science and engineering students in the early stages of their graduate careers. These highly-competitive, prestigious awards provide three years of support and are available to both Master's and Ph.D. students, as long as the degree is research-based. You can learn more at the NSF website: http://www.nsf.gov/funding/.

GEM FELLOWSHIPS

WPI is a member of the GEM consortium. Students who belong to underrepresented minority groups and want to pursue the Master's or Ph.D. degree in a field of science or engineering may apply for funding from the consortium to continue their studies at a GEM member school. More information can be found at the GEM website: http://www.gemfellowship.org/.

LOANS

Graduate students may also receive additional financial assistance in the form of federal and private student loan funds. In order to apply for these loans, students are required to submit the Free Application for Federal Student Aid (FAFSA) form. This form can be completed online at www.fafsa.gov. For more information you can contact the Office of Financial Aid website at http://www.wpi.edu/+finaid.

SCHOLARSHIPS AND GRANTS FOR GRADUATE STUDY ABROAD

RHODES SCHOLARSHIPS

Rhodes scholarships cover tuition, fees, and a stipend for two years of study in selected fields of science and engineering at Oxford University. They are awarded through state and regional competitions. Students interested in applying for a Rhodes Scholarship should begin to assemble their dossier during the Junior year. Applicants should have completed enough of the Bachelor's degree to assure its completion before their projected matriculation at Oxford. For more information, contact Prof. Peter Hansen in the Department of Humanities and Arts.

FULBRIGHT GRANTS

A wide variety of grants for graduate study abroad, usually for research toward the doctorate, is available through the federally-funded Fulbright Grants Program. For more information, contact Prof. Peter Hansen in the Department of Humanities and Arts.

PART-TIME GRADUATE PROGRAMS: ONLINE AND CAMPUS-BASED STUDY

Part-time graduate programs provide flexible educational opportunities for working students. Online, evening, and on-site corporate programs are taught by WPI faculty to serve the educational needs of technical and management professionals around the world.

Master of Science degrees for part-time students are offered in applied math, applied statistics, chemistry and biochemistry, computer and communications networks, computer science, financial math, industrial math, information technology, management, marketing and innovation, innovation with user experience, operations analytics and management, manufacturing management, operations analytics and management, supply chain management, physics, and system dynamics. The part-time MS is also offered in biomedical/clinical engineering, electrical and computer engineering, fire protection, manufacturing, materials science, mechanical engineering, supply chain management, and robotics engineering. The Master of Engineering degree can be completed part-time in biomedical, civil and environmental engineering. The Master of Business Administration (M.B.A.) is also offered on a part-time basis.

Graduate-level certificate programs are also available in some departments. For more details, see the Graduate Catalog.

Although the number of courses in each discipline may be limited in any given year, courses are scheduled so that part-time students are generally able to complete the requirements for the master's level degree in three to four years. Online and evening courses are offered year-round.

Students may enroll in individual graduate courses without being admitted to a graduate degree program. Those who wish to obtain a degree must apply for formal admission prior to completing two courses for graduate certificate programs and four courses for master's degree programs. Exceptions to this rule exist, so interested students should verify the actual number of courses they may take prior to matriculation within the specific program department.

A more detailed description of the part-time programs and of specific course offerings is available in the Graduate Catalog. Questions about each program should be related to the department heads or the graduate coordinators.

FIVE YEAR PROGRAMS

WPI offers unique five-year programs in Fire Protection Engineering, Industrial Mathematics, and Financial Mathematics. Each program begins with admission to the freshman year at WPI and ends with both a Bachelor's and Master's degree following five years of study.

High school students indicate their interest in one of these programs when they apply for admission to the undergraduate program at WPI. Applicants who are accepted into one of these programs will receive a letter of admission to both the undergraduate and graduate programs. Students in these programs are strongly urged to major in a field closely related to the graduate degree program. For example, most students choosing the Fire Protection Engineering program will have an undergraduate major in Mechanical or Civil Engineering. An academic advisor will assist students in course selection. Admission to the fifth year of study (i.e., the graduate program) is contingent on successful completion of the undergraduate degree and good academic standing.

For more information about these programs, contact the graduate coordinators or administrators in the Departments of Mathematics or Fire Protection Engineering.

GRADUATE COURSE LISTINGS

Graduate courses of interest to undergraduates are listed by title in the "Course Description" section of this catalog. A complete list is included in the graduate catalog. Most courses meet once per week in a fourteen-week format. The credits applied in either case are as shown to the right of the course title. Undergraduate students taking graduate courses may use the conversion factor: 1 graduate credit = 1/6 undergraduate unit. Students register for research or projects by using an individual program number rather than a course designation.

FOR MORE INFORMATION ON GRADUATE STUDY AT WPI

Consult the graduate catalog for more information about WPI's graduate programs. The departmental graduate coordinators are available to answer any program-specific questions you may have.

For more information about applying to WPI's graduate programs, please contact:

WPI Office of Graduate Admissions
www.grad.wpi.edu
grad@wpi.edu
Voice: 508-831-5301
FAX: 508-831-5717
Graduate Catalog online: http://www.wpi.edu/+gradcat

ADMISSION, EXPENSES, FINANCIAL AID AND HOUSING

Admission to WPI 242
Expenses 245
Financial Aid 247
Housing 251

SECTION 7

ADMISSION TO WPI

INTRODUCTION

WPI recruits, selects, and enrolls students who are the best match for our dynamic and distinctive educational offerings. Our admissions professionals review all students holistically taking into account each student's qualitative and quantitative materials within their specific context.

Selection for admission to WPI is based upon many factors including, but not limited to, academic preparation, grades, trends in academic performance, the personal essay, recommendations, co-curricular and extracurricular activities, and standardizes test scores (if submitted by the applicant). Candidates are allowed to submit supplemental material that they believe is relevant to the admissions committee's evaluation of their application.

VISITING & INTERVIEWING

WPI offers opportunities for students to explore campus, interview with admissions staff, and engage with students and faculty including:

- Daily information sessions & tours (weekdays & select Saturdays)
- Virtual online campus tour
- Fall Open House (for prospective & applying students)
- Personal interviews (on-campus and off-campus)
- Accepted Student Days (for accepted students)
- Envision overnight programs (for accepted students)

Visit www.wpi.edu/+visit for more information or to register for a visit or event.

Admissions Office Hours

The admissions office is open Monday – Friday 8:30am–5:00pm throughout the academic year. Summer hours (mid-May through the end of August) are 8:00am–4:00pm.

Contact Information

Phone: (508) 831-5286
Email: admissions@wpi.edu

ADMISSIONS REQUIREMENTS

The basic academic requirements for first-time first-year applicants include:

- Four years of English
- Four years of math (including pre-calculus)
- Two years of lab science

Other application requirements for the evaluation process include:

- Official high school transcript
- Recommendations from a teacher (preferably math or science) and a guidance counselor
- A personal essay

WPI is a test-optional university. Applicants to WPI are not required to submit SAT or ACT scores. Candidates who wish to have their test scores considered can either self-report their scores or send an official score report from the College Board or ACT. If applicants choose to self-report scores at the time of application, they must send official scores when enrolling at WPI. WPI's institutional code is 3969 for the College Board and 1942 for the ACT.

International students whose first language is not English are required to submit either TOEFL or IELTS scores.

APPLYING TO WPI

WPI is a member of the Common Application, and the Common Application is the exclusive method by which first year candidates apply to WPI. All first year candidates must complete their application no later than January 15 for consideration.

Application deadlines*:

Early Action	November 1
Early Decision I	November 1
Early Decision II	January 15
Regular Decision	January 15

Notification deadlines*:

Early Action	January 15
Early Decision I	December 15
Early Decision II	February 15
Regular Decision	March 15

*Dates are subject to change. Visit www.wpi.edu/admissions/undergraduate for the most up-to-date information regarding deadline and notification dates.

FINANCIAL AID

Students applying for financial aid must check the appropriate box on the application for admission to be considered for financial aid. Financial aid candidates should submit the College Scholarship Service (CSS) Profile Application and the Free Application for Federal Student Aid (FAFSA), which are available online at www.cssprofile.org and www.fafsa.gov. For all admission applicants, these forms should reach the WPI Office of Student Aid & Financial Literacy by the same deadline dates listed above for Admission applications. Financial Aid is available for U.S. citizens and/or permanent residents of the U.S. A limited amount of need-based financial aid is available for International Students. In order to apply for need-based assistance, international students must complete the international CSS Profile online at www.cssprofile.org.

APPLICATION FEE

A $65 application fee is required for all applicants. WPI endorses the fee waiver policy of the College Entrance Examination Board.

NOTIFICATION

All candidates for admission will receive an online acknowledgment of the receipt of their application. Admissions decisions are available exclusively through WPI's online portal and are not mailed to applicants. Decisions will be available to all applicants no later than April 1.

DECISION TO MATRICULATE

Accepted candidates must inform the college by 11:59pm on May 1 of their decision to matriculate and submitting a $500 non-refundable tuition deposit. Any deposits mailed in must be post-marked on or before May 1. WPI reserves the right to return deposits received after this date.

REVOCATION OF ADMISSION

In rare cases the admissions office may revoke the admission of an accepted or deposited student for reasons including (but not limited to):

- A change in academic performance
- Academic dishonesty
- Behavioral or disciplinary issues
- Actions deemed unacceptable by the admissions committee

ADVANCED PLACEMENT

WPI awards credit to students who score a score a “4” or “5” on most Advanced Placement Examinations. The Office of Academic Advising will notify such students of their earned credit by mail to the home address during early August. You can visit the Registrar’s Office web site www.wpi.edu/offices/registrar/policies-procedures/ap-credit for a complete list of AP credits for exams taken.

Humanities

The Humanities and Arts Department will accept a maximum of 1/3 unit of AP credit towards the Humanities and Arts requirement. AP credit beyond one course (1/3 unit) in the Humanities and Arts may be counted toward other requirements such as free elective credit or particular majors and minors at WPI. For most humanities disciplines, students who score a 4 or 5 in the AP test will receive credit in the relevant discipline. Special cases in language and studio art are explained below.

AP credit in languages

Students who score a 4 or higher on the College Board AP exam in Chinese language and culture, German Language, Spanish language, or Spanish literature, automatically receive 1/3 unit of credit in the language. This can be applied to the breadth component of the HUA Requirement or to the HUA language track option. In either case, the student will receive credit for one of the following Elementary 1000-level language courses and cannot enroll in that course for additional credit: CN 1541, GN 1511, SP 1523.

Students who took Arabic, Chinese, German, or Spanish in high school – but who do not earn AP credit for it at WPI – can get 1/3 unit retroactive credit for that language if they meet the following 3 criteria: 1) studied it for three or more years in high school and maintained at least a B average for all three years and; 2) place into at least the 2nd term of the appropriate WPI language sequence; and 3) successfully complete two terms of that language at WPI, earning grades of B or higher in both courses. The exception is Spanish: students studying Spanish must complete Intermediate I (SP 2521) and Intermediate II (SP 2522) with a grade B or higher. To request 1/3 unit retroactive language credit,please use the appropriate form on the Humanities and Arts website (https://www.wpi.edu/academics/departments/humanities-arts/resources). Students may receive credit for either the AP exam or 3 years of high school language study, but not both. For questions about this policy, please contact the Humanities and Arts Department.

AP Credit in studio art

Students who score a 4 or 5 in the AP test in studio art are eligible for HUA credit after a successful portfolio review by art faculty.

Computer Science

Advanced placement in computer science can be earned for the “Computer Science AP A” exam. Credit for CS 1000 is granted for scoring a “4” or “5” on the CS AP A exam. No credit will be granted for “Computer Science AP Principles” exam.

The Computer Science department advises CS Majors who earn a “4” or a “5” on the CS AP A exam to enroll in CS 1102 (Accelerated Introduction to Program Design). Students who wish to pursue a CS Minor after earning a “4” or a “5” on the CS AP A exam may consider enrolling in CS 2119 (Application Building with Object-Oriented Concepts) or CS 2301 (Systems Programming for Non-Majors).

Students who took CS AP Principles exam and have substantial programming experience should consult with the CS course instructors as to which course to take.

Natural Sciences

Students who pass the advanced placement test in Biology or Physics B with a “4 or 5” will be awarded 1/3 unit of advanced placement credit. This credit will show on the transcript as “L”. For students who score “4 or 5” in Physics C (Mechanics) will be awarded 1/3 unit in Physics 1110/ 1111. Students who score “4 or 5” in Physics C (Electricity and Magnetism) will be awarded 1/3 advanced placement credit for Physics 1120/1121. For those students who pass Physics B will be awarded 1/3 unit in Physics 1000. Students who score 4/5 on the Chemistry Advanced Placement Examination or 6/7 on the Chemistry International Baccalaureate Exam are automatically awarded 1/3 unit of credit for CH 1010. In addition, any student can earn credit for the general chemistry courses, CH 1010-1040, by achieving scores of 70 or better on course-specific examinations offered by the Department of Chemistry and Biochemistry. Exams must be taken in the order in which the courses are offered, and a student may not take any exam past the first failed exam. For example, a student who passes the CH 1010 exam but fails the CH 1020 exam is not eligible to take the CH 1030 exam. This student will receive credit for CH 1010 only. Students who receive AP or IB credit for CH 1010 are eligible to take the CH 1020 exam without having first passed the CH 1010 exam. Note this policy applies only to WPI students.

Mathematics

Students who pass the AB mathematics examination with a “4” or “5” will be awarded 2/3 unit of advanced placement credit for MA 1021 and MA 1022. Students with a “4” or “5” on the advanced placement BC exam will be awarded 1 unit advanced placement credit for MA 1021, MA 1022 and MA 1023. In the four-course 1021-1024 mathematics sequence, students who arrive at WPI prepared to start with the second (or third) course in the WPI sequence, and who successfully pass that course and the one that follows it, will be considered to have established advanced placement credit for the first one (or two) courses. To qualify for the credit, the two WPI calculus courses must be passed on first attempt during the student’s first year (by the end of term D). The courses credited retroactively will be listed by number without an assigned grade and will count toward the distribution requirement in mathematics.

Project Lead The Way (PLTW)

WPI awards credit to current WPI students who completed a PLTW Engineering course in high school, received a minimum of a “B” in the course, and earned on the PLTW End-of-Course Assessment either a stanine score of 6 or higher (before July 2018) or a minimum scale score of 410 for IED, 410 for POE, 420 for CEA, 430 for CIM, 450 for DE. WPI also honors PLTW transfer credits from other select PLTW university partners, such as RIT. Please visit the WPI Project Lead The Way web site (www.wpi.edu/+pltw) for more information and to apply for credit. A staff member will notify students of their earned credit..

NEW STUDENT ORIENTATION

During the week prior to classes, the Campus Center and Student Activities Department coordinates a comprehensive new student orientation program for all first-year and transfer students. New student orientation provides an introduction to the WPI experience, ranging from academic work and expectations and project-based education, to student life and campus activities. Led by upperclass student team leaders and faculty advisors, new students to WPI attend team meetings that are designed to familiarize them with the overall campus environment.

TRANSFER STUDENTS

Each fall, WPI welcomes applications from full- and part-time transfer students from accredited two- and four-year institutions. We look for candidates with demonstrated strength in math, science, and computer or engineering coursework; transfer admission to WPI is highly competitive. Candidates must be enrolled in, or have recently completed, courses in calculus and in two laboratory sciences at the time of application. Successful transfer candidates typically have a cumulative college GPA of 3.5 or higher. Additionally, successful transfer candidates have typically completed at least one full year of college (post high school graduation) by the time of intended enrollment. Transfer candidates must be in good academic and disciplinary standing at all institutions in which they have been an enrolled student.

Applicants should be aware of the accelerated pace of WPI's academic calendar, which consists of four, seven-week terms instead of two semesters. A full-time course load is defined as three courses per term with classes meeting four or five days per week, while a part-time course load may not exceed three total courses in two consecutive terms. All transfer students must enroll at WPI for a minimum of two full academic years in order to complete a degree. Additionally, undergraduate classes are only offered during the day.

Transfer Admissions & Financial Aid

The fall entrance application deadline is May 15th, with the review process typically beginning in March each year. Please note WPI does not offer a January application option. In addition to submitting the Application (available for transfer candidates after January 1st), transfer applicants should provide their official college transcripts for each post-secondary institution attended, a Mid-Term Report of coursework currently in progress, a final official high school transcript, two letters of recommendation (one must be from a college academic instructor), and the Transfer College Report. International transfer applicants must submit English translations and course-by-course evaluations (from a current NACES member) for all non-US transcripts, proof of English Language Proficiency, and Proof of Financial Ability (if accepted to WPI) demonstrating funding for the total cost of education and living expenses (an I-20 will not be issued without this form). Additional information about the transfer application process can be found at admissions www.wpi.edu/.

Transfer students may be eligible for need-based scholarship and loan funds from a variety of sources including WPI, the federal government, and some state government agencies. Financial aid is not available for part-time candidates or for international (non-U.S. citizen) transfer students. More information is available at www.wpi.edu/+finaid.

Transfer Agreements & Transfer Credit

WPI currently holds formal articulation agreements with specified programs of studies at both Quinsigamond Community College and Cape Cod Community College. However, WPI will grant appropriate transfer credit from any accredited two-year or four-year institution.

WPI is only able to offer a transfer credit evaluation once a transfer student is offered admission and enrolls at WPI and after enrollment for first year students, typically beginning in mid-May; Newly enrolled WPI students (both transfer and first-year) should send a transfer credit review request to transfer@wpi.edu, and provide college transcripts and course descriptions or syllabi for each course to be considered from work completed prior to their enrollment at WPI. The Transfer Admissions team coordinates the process with WPI faculty who evaluate the coursework to determine credit eligibility. Each academic department at WPI reviews courses under their program, and provides a decision to the Transfer Admissions team. Admissions communicates any credit updates to the WPI Registrar's Office as well as WPI Academic Advising. In general, courses that are the academic equivalent of a WPI course with a grade of a B or better will be considered for transfer credit. College-level and lab-based chemistry and biology, calculus, calculus-based physics with lab, engineering science, and most social science and humanities and arts courses are typically considered for transfer credit. To be eligible for credit review, the courses must be completed on a college campus taught by college instructors. Early college, early entrance programs, or college coursework provided in partnership with a college or university but offered at the high school taught by high school teachers are not eligible for credit at WPI, with the exception of Project Lead The Way (PLTW). Online coursework is also typically not eligible. Additional courses that are not transferable include pre-calculus, non-calculus based physics or engineering science, and computer courses in BASIC.

Humanities & Arts Requirement for Transfer Students

As part of the WPI Plan, all WPI students must complete the Humanities and Arts Requirement. As such, all transfer students should review their humanities and arts coursework accepted for transfer credit at WPI and plan with the Humanities and Arts Department's coordinator for transfer students to determine next steps towards the completion of the HUA Requirement. All transfer students entering WPI with fewer than two units of humanities and arts credit must complete thematically related work in humanities and arts. This will include an inquiry seminar or practicum to the extent that the overall humanities and arts credit totals two units. The HUA Requirement is considered fulfilled for transfer students who have completed the equivalent of two units of humanities and arts work prior to their matriculation at WPI. A Completion of Degree Requirement form (or CDR) must be submitted once the HUA Requirement has been satisfied. This form can obtained at the WPI Registrar's Office, and will be completed by the Humanities and Arts Department coordinator for transfer students. For those transfer students who have satisfied the HUA Requirement based on work completed at their previous institution(s) and who submit the approved CDR form to the WPI Registrar's Office will have this information posted to their student account. This process normally takes place prior to or during the first term of full-time enrollment at WPI.

INTERNATIONAL STUDENTS

The presence of international students serves as a means of strengthening the knowledge and understanding of foreign countries and cultures and is highly encouraged and supported at WPI. Programs and support services for international students and exchange programs are given high priority. As an institution of higher learning, WPI is dedicated to international education.

In addition to the standardized tests listed prior, international applicants must provide proof of English language proficiency. English language proficiency may be demonstrated by the official results of:

- TOEFL (Test of English as a Second Language)-Minimum score: 550 paper based or 80 internet based.
- IELTS (International English Language Testing System) 6.5 or higher with no band below 6.0.

THE ENGLISH AS A SECOND LANGUAGE (ESL) PROGRAM

The ESL Summer Institute is an intensive five-week non-credit course of study in English for specific purposes for international students and others whose first language is not English. This ESL program is designed to help prepare these international students for regular courses in engineering, science and technology before the regular academic year begins.

For students who need additional support during the regular academic year, the ESL Seminar, a tutorial course designed to help the student further strengthen linguistic skills, is offered.

During the regular academic year, ESL for Spouses is a noncredit course offered to interested partners accompanying WPI students and professors.

EXPENSES

ESTIMATED EXPENSES

Expenses for the 2020-21 year were not established at the time of this publication. They will be published via the web at a later date. For the 2019-20 year, the expenses were as follows:

Tuition	$51,604
Student Life Fee	316
Health & Wellness Fee	400
Total Tuition and Fees	$52,320
Room (Typical Freshman Double)	8,736
Board (7-Day, 19-Meal Plan)	6,566
Books and Supplies (Estimated)	1,000
Personal Expenses	1,200
New Student Orientation Fee	200
	$70,022

Basic tuition entitles full-time students to full academic and student services including counseling, placement and recreational facilities. Other costs must be anticipated, such as laundry, clothing, travel expenses, entertainment and personal expenses.

SPECIAL STUDENT

1/3 unit (3 credits) $4,299

Health insurance is required for all students. Students may waive their right to participate in the WPI health insurance plan if proof of comparable coverage is provided annually by completing a waiver online. For 2019-20, the cost was $1,252 for the academic year.

PAYMENT OF TUITION DEPOSIT

ENTERING STUDENTS

Payment of a nonrefundable $500 deposit is required upon acceptance of admission to WPI. The $500 will be credited to the student's tuition.

ENROLLMENT AND TUITION DUE DATES

Enrollment for students pursuing a baccalaureate degree will occur three times per year:

1. Fall semester-at the beginning of Term A.
2. Spring semester-at the beginning of Term C.
3. Summer session-at the beginning of Term E.

There will be no check-in at the start of Terms B and D, although a course change period will be available for students continuing from the previous term.

Special tuition features relative to Term E enrollment are available on the E-term web site.

Bills are electronically mailed twice per year, per semester. Fall bills will be mailed in July and are due in August. Spring bills are mailed in December and due in January. All respective due dates are listed on the eBill. Students who enroll two weeks prior to the start of a semester are required to pay at the time they register.

For E-Term (Summer) if a WPI student registers prior to a week before the first day of class they will receive an eBill, E-Term typically has two due dates, an E1 due date and an E2. If a student registers within one week before or after the start of the E-Term session payment is due at the time of registration. *Non-matriculated students, (not enrolled in a WPI degree program) payment is due at the time of registration. Failure to pay will result in being dropped from any course(s).*

FINANCIAL OBLIGATIONS, HOLDS, AND LATE FEES

*The college reserves the right to hold grades, official transcripts, registration and/or diploma for any student who has an outstanding financial obligation with the college.

Late fees will be assessed on balances not paid by the due dates.

A student may be administratively withdrawn due to an outstanding financial obligation for a term, which may require the student to apply for financial re-admission.

Students who elect to petition any charge on their Student Account must do so in writing prior to the final day of classes in the respective term (B term for Fall or D term for Spring). No late petition will be reviewed or approved if submitted after a term has commenced.

Failure to pay your financial obligation may result in the account being referred to an outside collection agency and reported to a credit bureau agency, which will negatively affect your credit rating. You will be responsible for all costs associated with the collection of this debt to the maximum amount allowed by Massachusetts general statutes.

* WPI fully supports the Veterans Benefits and Transition Act of 2018. Sec. 103 amends US code to prevent schools from penalizing Ch. 31 or 33 students if/when the VA is late making payments. WPI policy supports and agrees to the VA recommendations of the following while waiting for VA payments: WPI agrees to not prevent enrollment, charge a late penalty fee(s), require alternative or additional sources of funding or deny access to school resources.

OVERLOAD CHARGES

There will be a tuition surcharge on registration which contains academic overloads in excess of $2^1/_3$ (7/3) units per semester. Physical education and military science are not included in the determination of overloads. The overload charge will be based upon the total registration credit held by the student at the close of the initial course change period in B- and D-terms. (Please consult the Registrar's Office or the Office of the Bursar for current fees.) Fall overload billing will take place during Term B and spring overload billing during Term D. The current Term E charge system will not be affected.

TUITION CHARGES UPON WITHDRAWAL OR SUSPENSION

Tuition charges upon formal withdrawal from the college during each semester are:

	Charge
1. Withdrawal after enrollment but prior to first day of classes of a semester	Charged 0%
2. Withdrawal weeks 1 & 2	10%
3. Withdrawal week 3	20%
4. Withdrawal week 4	30%
5. Withdrawal week 5	40%
6. Withdrawal weeks 6-8	50%
7. Withdrawal week 9	60%
8. Withdrawal week 10	80%
9. Withdrawal week 11 and after	100%

To qualify for a reduction in tuition, students must submit an Official Withdrawal form to the Registrar's Office. The date of the student's last date of attendance determines the charge.

There is no reduction in tuition/fees in the case of withdrawal from individual courses.

Students who have paid full tuition for eight semesters may be allowed to enroll as part-time students on a per-course basis and be charged tuition accordingly. (Two summer terms enrolled as a full-time student may be counted as a semester.) Students must submit the Application for Part-time Status to the Registrar's Office at least two weeks before the beginning of the fall or spring semester.

Health insurance, health fee, and social fee are neither pro-rated nor refunded.

After all adjustments have been made, any balance due to WPI is payable immediately.

ROOM & BOARD CHARGES UPON WITHDRAWAL OR SUSPENSION 2018-19

	Charge
1. Withdrawal after enrollment but prior to first day of classes of a semester	Charged 0%
2. Withdrawal weeks 1 & 2	10%
3. Withdrawal week 3	20%
4. Withdrawal week 4	30%
5. Withdrawal week 5	40%
6. Withdrawal weeks 6-8	50%
7. Withdrawal week 9	60%
8. Withdrawal week 10	80%
9. Withdrawal week 11 and after	100%

FINANCIAL AID UPON WITHDRAWAL/ SUSPENSION

Students who withdraw or are suspended from WPI and are receiving any type of financial will have their funding adjusted based on their official withdrawal/suspension date and institutional, federal, and state refund calculations. If federal funds are required to be returned to the Federal Department of Education, they will be returned before any other forms of aid and in the following order per federal guidelines: Unsubsidized Federal Direct Loan, Subsidized Federal Direct Loan, Federal PLUS Loan, Federal Pell Grant, and Federal Supplemental Educational Opportunity Grant. WPI Scholarships (merit and/or need based) and WPI Institute Loans are then reduced up to the amount of remaining credit sources. Because each refund calculation is unique to a student's withdrawal date, costs incurred and aid he/she is receiving, students are encouraged to contact the WPI Office of Student Aid & Financial Literacy about their aid adjustments if they have any questions.

WPI is committed to assisting students and their parents in finding ways to finance the cost of a WPI education through financial aid assistance and private financing options. Central to WPI's program is the concept of financial need. This concept is based on the assumption that parents and students together accept the responsibility for educational expenses to the extent they are able. Over 94% of WPI undergraduates are receiving financial help from federal, state, and/or institutional resources (includes need and merit based aid). A combination of grants, loans and/or work study assistance from federal, state and WPI funding are allocated to students who demonstrate financial need. The proportion of grant, or "gift" assistance, versus loan and work, may be determined by the college on the following criteria: the magnitude of the financial need, the student's academic performance, and the availability of funds.

APPLICATION PROCEDURES – PROSPECTIVE STUDENTS

Students are required to file the Free Application for Federal Student Aid (FAFSA) and the CSS (College Scholarship Service) Profile Application. In the case of separation or divorce, the student's noncustodial parent must also complete a CSS Profile. Students list WPI's school code under the section on each form where it designates which schools are to receive the form. In addition, students whose financial aid applications are selected for verification* are required to submit additional documentation for themselves and their parents, if considered dependent. Generally, tax filers are required to either successfully utilize the IRS's Data Retrieval Tool on the FAFSA or submit a copy of their tax return transcript. Non tax filers are required to submit a copy of their W-2 statements as well as a non-filer statement from the IRS.

*Please visit www.wpi.edu/+faverification for more information on the verification process.

EARLY ACTION AND EARLY DECISION APPLICATION FOR FINANCIAL AID

Applicants must indicate on their admission application they are applying for financial aid. For those students applying for early action admission, the CSS Profile Application (and CSS Profile from Noncustodial parent, if applicable) can be submitted as early as October 1st, but no later than the posted Admission application deadlines. The FAFSA and the CSS Profile Application are available online at www.fafsa.gov and www.cssprofile.org.

Successful candidates for early action admission will be notified of financial aid eligibility on a rolling basis. Applicants will then have from the date of their aid eligibility letter until the candidates' common reply date, May 1st, to either accept or decline the aid offered.

REGULAR DECISION APPLICATION FOR FINANCIAL AID

Applicants must indicate on their admission application they are applying for financial aid. Successful candidates for admission will be notified of a financial aid decision in late March if a complete financial aid application has been submitted. Applicants will then have from the date of the financial aid decision until the candidates' common reply date, May 1st, to either accept or decline the aid offered.

To ensure a complete review, the WPI Office of Student Aid & Financial Literacy must receive the FAFSA and the CSS Profile Application by January 15th. Applications completed after this date will be reviewed subject to available funding. The Office of Student Aid & Financial Literacy encourages students to complete the FAFSA and the CSS Profile Application (and CSS Profile from Noncustodial parent, if applicable), when the FAFSA and CSS Profile Application open October 1st to ensure that WPI's filing deadline of January 15th is met.

UPPERCLASS APPLICATION FOR FINANCIAL AID

Upperclass students who receive need based financial aid must reapply for financial aid every year by completing the FAFSA. In a few cases, some upperclass students will also be required to submit the CSS Profile Application in addition to these requirements. Typically, upperclass students who will need to complete the CSS Profile Application are those whose parents are recently separated or divorced, students who are re-admitted to WPI, students whose custodial and noncustodial parents have changed since the prior academic year, and students who did not apply for need based financial aid in the prior academic year. The WPI Office of Student Aid & Financial Literacy reserves the right to request that a CSS Profile Application be completed by any upperclass student applying for need based financial aid.

Filing information on the FAFSA (and CSS Profile Application, if necessary) is due by April 15th. In addition, students whose financial aid applications are selected for verification* are required to submit additional documentation for themselves and their parents, if considered dependent. Generally, tax filers are required to either successfully utilize the IRS's Data Retrieval Tool on the FAFSA or submit a copy of their tax return transcript. Non tax filers are required to submit a copy of their W-2 statements as well as a non-filer statement from the IRS. The complete application provides consideration for grants, scholarships, loans and federal on-campus employment for the following academic year. Students and their parent(s) are expected to obtain and submit all requested forms in a timely manner for each year of planned enrollment. If any of the required forms are submitted late, there will be a delay in the student receiving an eligibility letter and there may be a reduction in his/her grant or scholarship eligibility for the year in which he/she is applying for need based financial assistance. The amount of financial aid upperclass students receive will depend on their academic performance from the prior academic year, their family's demonstrated financial need which is determined from the FAFSA, and the CSS Profile Application, if required.

*Please visit www.wpi.edu/+faverification for more information on the verification process..

TRANSFER STUDENTS

Transfer students may apply for financial aid eligibility beginning with their first term of matriculation and must indicate interest in financial aid on the admission application. Please note that financial aid is not available for part time or international (non-U.S. citizen) transfer students. Transfer aid applications will be reviewed based on the same documentation required for first year applicants and are packaged on a funds available basis. The FAFSA and CSS Profile (and CSS Profile from Noncustodial parent, if applicable) are due by May 15.

In addition, students whose financial aid applications are selected for verification* are required to submit additional documentation for themselves and their parents, if considered dependent. Generally, tax filers are required to either successfully utilize the IRS's Data Retrieval Tool on the FAFSA or submit a copy of their tax return transcript. Non tax filers are required to submit a copy of their W-2 statements as well as a non-filer statement from the IRS.

*Please visit www.wpi.edu/+faverification for more information on the verification process.

FORMS OF AID

FEDERAL PELL GRANTS

Federal Pell Grants are awarded to high need students from low and lower middle-income families. For the 2019-20 academic year these grants range from $657 to $6,195 per academic year. A Student Aid Report (SAR) is sent electronically to all students who file a Free Application for Federal Student Aid (FAFSA). The WPI Office of Student Aid & Financial Literacy will verify the data on the form, making corrections if necessary.

FEDERAL SUPPLEMENTAL EDUCATIONAL OPPORTUNITY GRANTS (FSEOG)

Federal SEOG funds are allocated to institutions by the Federal government. These funds, which are awarded to students as campus based grants, are awarded to high need students who are also eligible for the Federal Pell Grant.

FEDERAL DIRECT STUDENT LOAN

There are two types of Federal Direct Loans offered to students by the federal government: the Federal Direct Subsidized Loan and the Federal Direct Unsubsidized Loan. A student's federal financial need will determine which loan(s) he/she will be offered in the financial aid award.

Federal Direct Subsidized Loans are loans on which the federal government pays the interest while the student is enrolled in school at least half time and during periods of grace.

Students not eligible for the Federal Direct Subsidized Loan may borrow through the Federal Direct Unsubsidized Stafford Loan Program. In the Unsubsidized Loan Program, the federal government does not pay the interest on the loan. Rather, the student has the option to either pay the interest or capitalize it and postpone repayment of principal and interest until after graduation or falling below at least half time enrollment.

Repayment of both principal and interest for the Subsidized and Unsubsidized Federal Direct Loans begins at the end of the 6 month "grace period" following the last day of enrollment or withdrawal from school. Students have ten years to repay their Federal Direct Loans.

Students must file a FAFSA so that WPI can determine need-based eligibility for the Federal Direct Loan. The federal government sets annual borrowing limits according to the student's year in school or grade level. As of the 2012-13 academic year, first year students may borrow up to $3,500, second year students up to $4,500 and third and fourth year students up to $5,500. Students cannot borrow in excess of $23,000 over the life of their undergraduate education. All qualifying students may also borrow $2,000 in the Unsubsidized Loan per year.

The WPI Office of Student Aid & Financial Literacy recommends and approves the amount a student may borrow for the Subsidized and Unsubsidized Federal Direct Loan. For all new borrowers, a Master Promissory Note (MPN)must be completed. This may be done electronically or on paper. Students will be notified of the availability of the note to be signed. The Master Promissory Note only needs to be signed once during the student's undergraduate time at WPI.

FEDERAL WORK STUDY PROGRAM

Federal Work Study (FWS) funds are allocated annually to colleges who offer federally funded work opportunities to high need financial aid applicants. FWS is included in the financial aid eligibility letter to students if they qualify for these funds. If a student accepts a FWS offer, he/she may work a maximum of 10 hours per week at the current MA State minimum wage.

Students who are awarded and accept the FWS funding are expected to complete 15 hours of community service during the academic year. In order to meet this requirement, students can obtain information on various community service opportunities from the WPI Student Activities Office (SAO). Approval of community service sites and hours of work must be granted by the WPI Office of Financial Aid or the Student Activities Office before students can begin work.

Students awarded FWS funding can choose to do one of the following:

1. Work on campus in an academic or administrative office during the academic year. During the year, the student also needs to work in a WPI SAO approved community service position for fifteen hours. The WPI SAO will work with students to find available opportunities to meet this requirement.
2. Work on or off campus in a WPI SAO approved community service position during the academic year. Students who work during the academic year in a community service position will meet their required 15 hours of community service in this position.

Obtaining a FWS position (and the required 15 hours of community service) either on or off campus is the responsibility of the student. Available FWS positions are posted at the beginning of each academic year on the WPI Human Resources Website: https://www.wpi.edu/student-experience/resources/student-employment. FWS earnings are paid by direct deposit on a bi-weekly basis to the student employee; they cannot be deducted from your tuition bill. Work is available in a variety of academic, administrative, or community service settings on and off campus. The off campus positions are community service positions and must be set up through SAO. Students who work in community service positions are paid current MA State minimum wage per hour in order to cover travel expenses to and from their jobs. The amount of FWS funds offered in a student's award letter indicates maximum earnings allowed, but is not a guarantee. The best procedure is to take an available position at the start of the academic year and work as much as the schedule allows up to the maximum 10 hours per week. If a student declines an offer of work, it will not affect the other components of his/her award package. However, please note that due to limited funding, if a student declines FWS funding or employment, this fund will not be renewed in future academic years. In addition, if a student earns less than $500 in

FWS funds during the academic year this fund is awarded or fails to complete the required 15 hours in community service, his/her FWS funding will not be renewed in future years. Please note that you can also lose your eligibility for FWS funds in future years if your financial need decreases or you do not meet the financial aid application deadline.

Students are prohibited from FWS employment if one of the following situations occurs: the student falls below the WPI established satisfactory academic progress levels for retention of aid, the student enrolls on a less than full time basis, or the student registers as a part-time/"Special Student."

STATE SCHOLARSHIP PROGRAMS
The MASSGrant is awarded to Massachusetts residents whose combined family contribution falls within state-determined parameters. Students must file the FAFSA by the state-designated deadline and follow all state program procedures to apply.

Massachusetts has reciprocity agreements with Pennsylvania and Vermont. These states allow their residents attending institutions in Massachusetts to "carry" need-based state grants into Massachusetts. Awarding from other state scholarship programs depends on annual state funding levels.

The Massachusetts Gilbert Matching Grants Program is allocated annually to WPI. These funds are awarded to Massachusetts residents who fall within a certain financial need.

STATE FUNDED STUDENT LOAN PROGRAMS
The Commonwealth of Massachusetts provides the Massachusetts No Interest Loan (MA NIL) Program through annual allocations to participating colleges and universities. Students who file the FAFSA and meet state eligibility criteria are eligible for the Massachusetts No Interest Loan on a funds available basis.

WPI COLLEGE SCHOLARSHIP
WPI awards College Scholarships and other restricted or endowed "gift" assistance, to students who have a demonstrated financial need based on review of the completed financial aid application, including the FAFSA, the CSS Profile Application (if first year applicant), IRS Data Retrieval Tool, and W-2 forms (if selected for verification). WPI gift aid may be combined with federal and state grants to make up a student's total portion of "gift" assistance, before loans and work are packaged.

WPI INSTITUTE STUDENT LOAN PROGRAM
The WPI Institute Loan is an institutional need-based loan awarded to students. Repayment of the principal and interest begins 9 months after the last day of enrollment or withdrawal from college.

FEDERAL DIRECT PLUS LOANS
Federal Direct PLUS Loans are available annually to parents of dependent undergraduate students. Repayment begins when the funds are advanced to the school with the option to defer repayment until after the student graduates or falls below half time enrollment status. Parents have 10 years to repay the Federal Direct PLUS Loan.

WPI DEPARTMENT-FUNDED WORK PROGRAM
Students who are not eligible for Federal Work Study funds may seek employment opportunities through departments or offices on campus that set aside funds for hiring undergraduate employees. These employment funds vary from year to year in terms of monies available or the number of students allowed per department/office. Students may also inquire about department-funded summer positions on campus.

FINANCIAL AID POLICIES

Financial aid is awarded one year at a time. Aid applicants are required to reapply annually by the beginning of Term D. An annual review of each applicant's financial need is assessed to assure that aid is renewed equitably as different circumstances cause needs to change. The WPI Office of Student Aid & Financial Literacy determines a student's financial need through a review of the completed financial aid application. Financial aid eligibility letters are mailed to upperclass students in early July for the following academic year.

STUDENT CONTRIBUTION
It is expected that the student's family will contribute its maximum financial effort and that the student will also make a maximum effort through savings from annual earnings and by accepting a proportion of financial aid in the form of loans and/or in-school employment, if eligible. Students at WPI are expected to contribute a minimum $2,750 each academic year from summer or other annual earnings. While this minimum student contribution is used, the WPI Office of Student Aid & Financial Literacy must review previous calendar year student earnings and student savings/assets as the basis for determining the annual student contribution.

INDEPENDENT/DEPENDENT STUDENT STATUS
WPI believes that the primary responsibility for an undergraduate education lies with the student and parent(s), to whatever extent possible. Therefore, all undergraduates applying for WPI institutional funds are required to provide parental information regardless of federal dependency status.

Although a student may meet federal guidelines to be considered an independent student, and therefore receive federal funds as an independent student, the ability of parents to assist their children, regardless of age and dependency status, is a factor WPI considers in determining eligibility for institutional need-based grants. Because of this, the WPI Office of Student Aid & Financial Literacy will require parental information from all students applying for need based institutional aid.

AID RETENTION/PROGRESS TOWARD A DEGREE
There are four key elements to the retention of eligibility for Institutional (WPI) financial aid as it relates to academics:

1. All full time students are expected to register and enroll in 36 credits per academic year*. Students must pass a minimum of 33 academic credits to keep the same level of funding the following year. Please note that AP courses, transfer credit, incompletes or extensions cannot be counted in the number of credits passed. The student is responsible for resolving any incomplete grades with the faculty member assigning the grade.

Federal and/or State Financial Aid
For retention of federal and/or state financial aid funding. Please refer to these aid policies at https://www.wpi.edu/admissions/tuition-aid/applying-for-aid/policies.

WPI Need Based Scholarships
WPI need based scholarships awarded to students will not increase in future academic years regardless of changes in a student's financial need. However, student's WPI need based scholarships can decrease based on a lower financial need and/or poor academic performance (from the prior academic year).

WPI Merit Scholarships
WPI merit scholarships will not increase or decrease based on changes to a student's financial need. However, a student's merit scholarship will decrease or be eliminated if a student does not pass a minimum of 33 academic credits per year.

2. Eligibility for consideration for all types of financial aid for the following academic year is lost if a student is placed on Academic Probation (end of B or D term).

Financial Aid Appeals
Students placed on Academic Probation or Federal Financial Aid Suspension may, in cases which involve unusual and extenuating circumstances such as documented medical problems, file a financial aid petition with the WPI Office of Student Aid & Financial Literacy. Financial Aid Appeals can be obtained in the WPI Office of Student Aid & Financial Literacy (2nd floor Bartlett Center) or online at https://www.wpi.edu/+faforms. The petition will be reviewed by the Financial Aid Appeal Committee. Determination on financial aid appeals will be made on a case by case basis.

3. Regardless of academic progress status, eligibility for WPI financial assistance is available for the shorter of the two following periods: 16 terms (4 years) of enrollment at WPI, as a full time or part time student, (NOT 16 terms of receiving financial aid), or completion of your Bachelor Degree requirements at WPI.

4. Students must be enrolled full time to be eligible for WPI need based and merit bases scholarship funding, as well as most federal and state grant programs and work study. A student is considered to be a full time student if they are being charged full time tuition and fees. Students are responsible for knowing their enrollment status and should enroll in the number of credits per year necessary to maintain their aid eligibility.

PLEASE NOTE: With the exception of the Federal Direct Loan, the Global Scholar Stipend, and the Foisie Scholar Stipend programs, financial aid is not available for enrollment during term E (Summer School) at WPI. This includes all forms of assistance including WPI Merit Scholarships. If you enroll during term E and borrow a Federal Direct Loan, the amount you borrow will be reduced from your Federal Direct Loan eligibility for the next academic year (terms A-D).

**there are exceptions such as students on an approved reduced course load. Please contact the Office of Student Aid & Financial Literacy if you have concerns.*

INTERNATIONAL STUDENTS
International students (who do not have official documentation of Permanent Residence Status in the United States) are ineligible for all sources of federal and state aid administered by the WPI Office of Student Aid & Financial Literacy. Limited scholarships are available for entering international students through the WPI Office of Student Aid & Financial Literacy.

ALTERNATIVE FINANCIAL PROGRAMS

Alternate financing programs are available to many students and their families who do not apply for aid or who need additional resources beyond federal, state, and institutional financial aid offered. WPI offers the TMS (Tuition Management Systems) payment plan which allows parents to pay their annual charges over 12 months rather than in two semester payments. Students and parents are encouraged to contact the WPI Bursar's Office for further information on the TMS payment plan option.

There are many long-term financing programs available to assist students and their families in spreading their educational costs over 10 to 20 years. Many of these loans allow students and their families to borrow the difference between the cost of attendance determined by the college and total financial aid received for the academic year.

Please contact the WPI Office of Student Aid & Financial Literacy or visit https://www.wpi.edu/admissions/tuition-aid/types-of-aid/loans-financing.

FEDERAL PLUS LOANS
Federal PLUS Loans are available annually to parents of dependent undergraduate students. Repayment begins when the funds are advanced to the school with the option to defer repayment until after the student graduates or falls below half time enrollment status. Parents have 10 years to repay the Federal PLUS Loan.

RESERVE OFFICER TRAINING CORPS (ROTC) SCHOLARSHIPS

ARMY ROTC SCHOLARSHIP PROGRAM
For information on Army ROTC Scholarships, please contact the Army ROTC office at WPI at (508) 831-5268.

NAVAL ROTC SCHOLARSHIP PROGRAM
For information on Navy ROTC Scholarships, please contact the Naval ROTC Unit at Holy Cross College in Worcester (508) 832-2433.

AIR FORCE ROTC SCHOLARSHIP PROGRAM
For information on Air Force ROTC Scholarships, please contact the WPI Department of Aerospace Studies at WPI at (508) 831-5747.

PLEASE NOTE THE COMBINATION OF ALL SOURCES OF AID CANNOT EXCEED A STUDENT'S BUDGETED COST OF ATTENDANCE.

RESIDENCE HALLS

WPI provides its undergraduate students with a variety of housing options. The WPI residence halls offer first year students a choice of single, double, triple, and quadruple occupancy rooms as well as suites designed for four to eight persons.

Residence hall living at WPI offers opportunities that can be a valuable part of higher education. For this reason, on-campus housing is required for all first-year students. First-year students admitted for Term A, who meet all application deadlines, are guaranteed housing in the residence halls for that entire academic year.

There are also a variety of on campus upperclass student housing options. These include three, four, five and seven person apartments, residential houses, as well as traditional residence hall environments. Off campus housing alternatives include rooms in homes, apartments and community from home. Additionally for Fraternity and Sorority members there is Greek Chapter Housing available. Upperclass students are not guaranteed on-campus housing. The Housing and Dining Contract is a legally binding contract which extends from the beginning of Term A through Term D as long as the student is enrolled at WPI.

RESIDENCE HALL STAFF

Resident Advisors (RAs) are the core of the residential life staff in the residence halls. RAs serve as a source of assistance in resolving students' academic, personal, and social concerns. They plan and implement social and educational programs in the halls, and enforce all WPI policies and regulations in an effort to develop an effective living-learning environment in the residence halls.

The administrative responsibility for the operation of the residence halls rests with the professional staff in Residential Services. They counsel and advise students, work with maintenance and dining hall staffs, and handle many administrative processes for students living on campus.

OCCUPANCY

Residence halls normally open at 9:00 a.m. four days before Term A begins and close at 12:00 noon two days after the last day of classes for Term D. Housing and food service privileges are not transferable, nor may any person take up de facto residence without paying rent. The traditional residence halls will be closed during the December recess period. Apartment style residence halls remain open during the December recess period, but students must register to maintain access.

FURNISHINGS AND FACILITIES

Students are responsible for the neatness and cleanliness of their rooms. Residence halls are furnished with a twin-size bed, a desk and chair, closet space, and drawer space for each student. All residence halls are smoke free environments. Data network services and cable television are included in room rates. Residents provide their own pillows, linens, blankets, and other personal furnishings.

ID Card and Coin-operated laundry facilities are available on the campus.

The following are some of the things not permitted in the residence halls:

- Sale, use or possession of illegal drugs
- Pets, except small fish
- Refrigerators larger than 4.3 cubic feet in size, 3D printers
- Gambling
- Use of alcoholic beverages in violation of Massachusetts State Laws
- Firearms, weapons, explosives, incendiary or toxic chemicals, starting pistols, paint ball guns, knives
- Cooking, except in kitchen areas provided
- Candles or other flame-emitting devices
- Smoking of any kind

For a complete copy of the housing and dining contract, please visit the WPI website.

Mail and express packages should be addressed to the student by name, and box number, WPI, 100 Institute Road, Worcester, MA 01609-2280.

ROOMMATES

One of the most memorable aspects of campus life can be the relationship you will build with your roommate(s). Roommates often find that a meaningful relationship is developed through the sharing of thoughts and feelings; in other words, communication. We encourage you to be as open as possible so that you and your roommate can begin early to create a relationship based on respect and understanding. This relationship can help make residence hall living one of the most enjoyable part of your college career.

ROOM CHARGES

Since room and board rates for 2020-2021 were not established at the time of this publication, they will be announced separately.

Room Rates for 2019-2020
(*Note: Room rates listed are for the entire academic year*)

RESIDENCE HALLS	**FULL YEAR**
Daniels, Institute, Morgan, Riley, Messenger, Stoddard, Founders, Trowbridge	
Double, Triple, Quad	$8,736
Single	$9,242
East and Faraday Halls	
Double	$9,778
Single	$10,208
Studio	$10,342

APARTMENTS	**FULL YEAR**
Triple	$8,856
Double	$9,334
Single	$9,850

Note: Each apartment, East and Faraday location, is equipped with basic furnishings including stove and refrigerator.

RESIDENTIAL HOUSING	FULL YEAR
Elbridge, Hackfield, Schussler	
Triple	$8,856
Double	$9,334
Single	$9,850

Payment for housing and food service fees are made in two installments, one each at the beginning of Terms A and C. Reduced charges, if applicable, will be processed according to the established withdrawal policy of the college. Students entering the residence halls other than at the beginning of Term A or C will be issued a prorated billing for the period. This bill must be paid in full prior to occupancy.

Students are expected to care for the physical facilities of the residence halls. Damage to the facilities beyond the normal wear and tear shall be the financial responsibility of the residents. Damage to common areas of the residence halls will be divided among residents of that wing, floor, or building.

First year students can expect to receive a link to the Housing and Dining Application in June, after their $500 tuition deposit is received by the Office of Admissions.

First Year students should be prepared to select their housing through the online housing selection service in early to mid-July.

MEALS

Students residing in Morgan, Daniels, Riley, Stoddard, Trowbridge, Messenger, Institute and Founders are required to participate in one of the four meal plans. All other students are welcome to purchase a meal plan as well. The MEALS PLUS PLANS are a combination of traditional meal plans plus additional funds to be utilized at the student's discretion.

Once a student has contracted for food service, this is a legally-binding agreement, and students are obligated to assume financial responsibility for the entire academic year.

Board Plan Rates for the 2019-2020 academic year
(Note: Students are required to be on a meal plan for the entire academic year)

MEAL PLAN	BONUS POINTS	FULL YEAR
19	$75 Bonus Points (per semester)	$6,566
14	$175 Bonus Points (per semester)	$6,566
Gompei 200	$100 Bonus Points (per semester)	$6,566
VIP	$100 in Bonus Points (per semester)	$7,660

Descriptions of the board plans are available at: http://www.dineoncampus.com/wpi

OFF-CAMPUS LIVING

After the first year, on-campus housing is not guaranteed, so if you decide to look for an off-campus apartment, make plans well in advance. Information is available on the WPI website for you to research questions about small claims court, housing codes, leases, tenants' rights, etc. The following are a few hints for you as you begin your search for off- campus housing.

Leases: Contract periods for off-campus housing vary in length, from twelve-month and nine-month to summer only and three-month leases. As you consider various places, find out what types of leases are available.

Be Prepared: You'll want to plan realistically for expenses such as utilities, transportation, repairs, laundry, and food. Also, try to pick your roommates carefully and ahead of time.

LODGING LAWS

You should also be aware that the City of Worcester has a zoning code that prohibits more than three unrelated persons living together unless the landlord or owner has obtained a lodging house license .

TRUSTEES ADMINISTRATION AND FACULTY

Trustees, Administration and Faculty 254
Trustees 254
Administration 256
Faculty 257
Index 280
Policies & Practices 284
Currency of Information 284
Accreditation 285
Directions 285
Campus Map 286

SECTION 8

TRUSTEES

The administration of the college is entrusted to a Corporation consisting of not less than 12 members, consisting of life, ex-officio, at-large and alumni members. Emeriti members are elected by the Corporation in an advisory capacity. (Dates in parentheses following each name indicate year of election to membership.)

OFFICERS OF THE CORPORATION

CURRENT MEMBERS

ADMINISTRATION

Numerals following name indicate year(s) of initial appointment.

LAURIE A. LESHIN (2014)
University President
B.S., Arizona State University, 1987;
M.S., California Institute of Technology, 1989; Ph.D., 1994.

DAVID A. BUNIS (2017)
Senior Vice President and General Counsel
Secretary of the Corporation
B.A., Brandeis University, 1983;
J.D., Boston University, 1987.

PHILIP N. CLAY (1993)
Vice President, Student Affairs
B.A., St. Lawrence University, 1982;
M.A., Binghamton University, 1986.

MAUREEN DEIANA (2010)
Assistant Vice President, Chief Marketing Officer
B.S., Lesley University, 1993.

DANA L. HARMON (2002)
Director, Physical Education, Recreation and Athletics
B.A., Bellarmine College, 1987;
M.S., University of Massachusetts/Amherst, 1994.

MICHELLE JONES-JOHNSON (2016)
Vice President for Talent Development and Chief Diversity Officer
B.A., University of Michigan, 1989;
M.A., University of Phoenix, 1995;
M.B.A., Syracuse University, 2010.

WILLIAM J. MCAVOY (2011)
Vice President for University Advancement
B.S. University of Connecticut, 1978;
M.P.A., Suffolk University, 1987.

AMY M. MORTON (2010)
Vice President, Chief of Staff
B.A., Providence College, 1990.

PATRICIA L. PATRIA (2018)
Vice President for Information Technology and
Chief Information Officer
M.B.A., Suffolk University.

JEFFREY S. SOLOMON (2005)
Executive Vice President/CFO
Treasurer of the Corporation
B.S., Bentley College, 1985;
M.S., Brandeis University, 2001.

WINSTON O. SOBOYEJO (2016)
Senior Vice President and Provost, Ad Interim
B.sc., King's College, London, 1985;
Ph.D., Churchill College, Cambridge University, England, 1988.

BOGDAN M. VERNESCU (1991)
Vice Provost for Research
Professor, Mathematical Sciences
B.S., University of Bucharest, 1982; M.S., 1982;
Ph.D., Institute of Mathematics - Bucharest, 1989.

ACADEMIC AFFAIRS

TERRI ANNE CAMESANO (2000)
Dean of Graduate Studies;
Professor, Chemical Engineering
B.S., University of Rochester, 1995;
M.S., University of Arizona, 1997;
Ph.D., Pennsylvania State University, 2000.

ARTHUR C. HEINRICHER, JR. (1992)
Dean of Undergraduate Studies;
Professor, Mathematical Sciences
B.S., University of Missouri/St. Louis, 1980;
Ph.D., Carnegie Mellon University, 1986.

JEAN KING (2017)
Peterson Family Dean of Arts and Sciences;
Professor of Biology and Biotechnology
B.S., St. Francis College, Brooklyn 1979;
M.S., City University of New York 1982;
Ph.D., New York University 1988.

JOHN A. MCNEILL (1994)
Professor, Electrical and Computer Engineering,
and Interim Dean of Engineering
A.B., Dartmouth College, 1983;
M.S., University of Rochester, 1991;
Ph.D., Boston University, 1994.

KENT RISSMILLER
Dean, Interdisciplinary and Global Studies Division, ad interim;
Associate Professor, Social Science and Policy Studies
A.B., Muhlenberg College, 1976;
J.D., Franklin Pierce Law Center, 1980;
M.A., Syracuse University, 1981; Ph.D., 1986.

WINSTON O. SOBOYEJO (2016)
Bernard M. and Sophia Gordon Dean of Engineering;
Professor, Mechanical Engineering and Biomedical Engineering
B.Sc., King's College, London, 1985;
Ph.D., Churchill College, Cambridge University, England, 1988.

STEVEN S. TAYLOR (2002)
Professor and Dean ad interim Foisie Business School
B.S., MIT, 1982;
M.A., Emerson College, 1993;
Ph.D., Boston College, 2000.

RICHARD F. VAZ (1983)
Co-Director, Center for Project-Based Learning;
Professor, Electrical and Computer Engineering and IGSD
B.S., Worcester Polytechnic Institute, 1979;
M.S., 1984; Ph.D., 1987.

BOGDAN M. VERNESCU (1991)
Vice Provost for Research;
Professor, Mathematical Sciences
B.S., University of Bucharest, 1982; M.S., 1982;
Ph.D., Institute of Mathematics - Bucharest, 1989.

SUZANNE L. WEEKES (1998)
Interim Associate Dean of Undergraduate Studies
Professor, Mathematical Sciences
B.S., Indiana University, 1989;
M.S., University of Michigan, 1990; Ph.D., 1995.

KRISTIN K. WOBBE (1995)
Co-Director of the Center for Project Based Learning and Director of the Great Problems Seminars Program
Professor, Chemistry and Biochemistry
B.A., St. Olaf College, 1983;
Ph.D., Harvard University, 1991.

ACADEMIC DEPARTMENT HEADS

LT COL JACK SKILES III
Air Force Aerospace Studies

JOSEPH B. DUFFY
Biology and Biotechnology

KRISTEN BILLIAR
Biomedical Engineering

DIANE M. STRONG, AD INTERIM
Business

SUSAN ROBERTS
Chemical Engineering

ARNE GERICKE
Chemistry and Biochemistry

CARRICK EGGLESTON
Civil and Environmental Engineering

CRAIG E. WILLS
Computer Science

DONALD R. BROWN, AD INTERIM
Electrical and Computer Engineering

ALBERT SIMEONI
Fire Protection Engineering, ad interim

KATHRYN MONCREIF
Humanities and Arts

LUCA CAPOGNA
Mathematical Sciences

JAMAL S. YAGOOBI
Mechanical Engineering

LTC ADAM D. HEPPE
Military Science

DANA L. HARMON
Physical Education

DOUGLAS T. PETKIE
Physics

EMILY M. DOUGLAS
Social Science and Policy Studies

FACULTY

(As of January 2018)
Numerals following name indicate year(s) of initial appointment.

Generally, in this listing, faculty with the titles "associate professor" or "professor" are tenured, and with the title "assistant professor" are on the tenure track. Faculty with titles other than these three are full-time but not tenured or tenure track.

CURTIS ABEL (2015)
Professor of Practice
B.S., M.E., Ph.D., Carnegie Mellon University; 1985, 1991;
Postdoctoral Fellow in Engineering Design, Cambridge University, 1994;
M.B.A., Cornell University 2000.

JONATHAN P. ABRAHAM (2004)
Professor of Practice, Mathematical Sciences
B.S. University of Iowa, 1980;
F.S.A., Society of Actuaries, 1991.

LAILA ABU-LAIL (2011)
Assistant Teaching Professor, Civil and Environmental Engineering
B.S., Jordan University of Science and Technology, Jordan, 2003;
M.S., Worcester Polytechnic Institute, 2006;
Ph.D., Worcester Polytechnic Institute, 2011.

DAVID S. ADAMS (1984)
Professor, Biology and Biotechnology
B.S., Oklahoma State University, 1974;
M.S., University of Houston, 1976;
Ph.D., University of Texas, 1979.

WILLIAM A. B. ADDISON, JR. (1986)
Associate Professor, Humanities and Arts
B.A., University of South Carolina, 1965;
M.A., University of Virginia, 1967;
M.Phil., Columbia University, 1974; Ph.D., 1986.

MAHDI AGHELI-HAJIABADI (2013)
Assistant Research Professor, Mechanical Engineering
B.Sc., Isfahan University of Technology, Iran, 2006;
M.Sc., Tarbiat Modares University, Iran, 2009;
Ph.D., Worcester Polytechnic Institute, 2013.

EMMANUEL O. AGU (2002)
Professor, Computer Science
B.Eng., University of Benin, Nigeria, 1994;
M.S., University of Massachusetts/Amherst, 1996; Ph.D., 2001.

JOSEPH R. AGUILAR (2018)
Assistant Teaching Professor, Humanities and Arts
B.A., Westmont College, 2001;
M.F.A., Oregon State University, 2007;
Ph.D., University of Missouri, 2013.

LEONARD D. ALBANO (1992)
Associate Professor, Civil and Environmental Engineering
B.S., Tufts University, 1982;
M.S., Northwestern University, 1983;
Ph.D., Massachusetts Institute of Technology, 1992, P.E.

DIRK ALBRECHT (2013)
Associate Professor, Biomedical Engineering
B.S., University of California-San Diego, 1997;
M.S., 2001; Ph.D., 2005.

SAKTHIKUMAR AMBADY (2013)
Associate Teaching Professor, Biomedical Engineering;
Director, MQP Labs and Undergraduate Teaching Facilities
D.V.M., Andhra Pradesh Agricultural University, India, 1984;
Ph.D., University of Massachusetts, Amherst, 1996.

MIHNEA ANDREI (2019)
Post-Doctoral Scholar, Mathematical Sciences
B.S., Worcester Polytechnic Institute, 2014;
M.Sc., Worcester Polytechnic Institute, 2014;
Ph.D., University of California at Santa Barbara, 2019 (expected)

DIRAN APELIAN (1990)
Professor, Mechanical Engineering;
Howmet Professor of Engineering;
Director, Metal Processing Institute
B.S., Drexel University, 1968;
Sc.D., Massachusetts Institute of Technology, 1972.

PADMANABHAN K. ARAVIND (1984)
Professor, Physics
B.S., Delhi University (India), 1971; M.S., 1973;
Ph.D., Northwestern University, 1980.

1 LT. CYNTHIA L. ARCHAMBEAU (2016)
Air Force and Aerospace Studies
B.S., UMASS Amherst, 2012.

JOSÉ M. ARGÜELLO (1996)
Professor, Chemistry and Biochemistry;
Walter and Mariam B. Rutman Distinguished;
Professorship in Chemistry
B.S., National University of Cordoba, Argentina, 1979;
Ph.D., National University of Rio Cuarto, Argentina, 1985.

ANDREA ARNOLD (2017)
Assistant Professor, Mathematical Sciences
B.S., Duquesne University of the Holy Spirit, 2009;
Ph.D., Case Western University, 2014.

HOLLY K. AULT (1983)
Associate Professor, Mechanical Engineering
B.S., Worcester Polytechnic Institute, 1974; M.S., 1983;
Ph.D., 1988.

MARJA BAKERMANS (2013)
Associate Teaching Professor, Global School and Biology and Biotechnology
B.S., Bucknell University, 1996;
M.S.,The Ohio State University, 1996; Ph.D., 2008.

THOMAS BALISTRIERI (2015)
Assistant Teaching Professor, Interdisciplinary and Global Studies
M.A., Pacific Lutheran University, 1975;
Ph.D., Mississippi State University, 1981.

ISA BAR-ON (1982)
Professor, Mechanical Engineering
B.S., Hebrew University of Jerusalem, 1974;
M.S., 1977; Ph.D., 1984.

SCOTT BARTON (2012)
Associate Professor, Humanities and Arts
B.A., Colgate University, 1998;
M.M., Brooklyn College Conservatory of Music, 2006;
Ph.D., University of Virginia, 2012.

JOSEPH E. BECK (2008)
Associate Professor, Computer Science
B.S., Carnegie Mellon University, 1993;
Ph.D., University of Massachusetts, Amherst, 2001.

MELISSA BELZ (2013)
Associate Teaching Professor, IGSD
B.S., University of Massachusetts, 1995;
M.A.,Oxford Brooks University, 2000;
Ph.D., Kansas State University, 2012.

JOHN A. BERGENDAHL (2000)
Associate Professor, Civil and Environmental Engineering
B.S., University of Connecticut, 1985; M.S., 1996;
Ph.D., 1998.

NICHOLAS BERTOZZI (2016)
Senior Instructor, Robotics Engineering
B.S., Northeastern University, 1977; M.S., 1982.

SHAMZNAZ VIRANI BHADA (2013)
Assistant Professor, Electrical and Computer Engineering
B.S., University of Pune, India, 1999;
M.S., Wright State University, Dayton, 2002;
Ph.D., University of Alabama, Huntsville, 2008.

MEHUL BHATIA (2017)
Assistant Teaching Professor, Mechanical Engineering
B.E., Sardar Patel University, India, 2007
M.S., New Jersey Institute of Technology, 2008;
Ph.D., Arizona State University, 2013.

FREDERICK BIANCHI (1994)
Professor, Humanities and Arts
B.A., Cleveland State University, 1980;
M.S., Ball State University, 1982; Ph.D., 1985.

ROSHANAK BIGONAH (2009)
Senior Instructor/Lecturer, Humanities and Arts
B.A., Worcester State College, 1989;
M.Ed., Lesley University, 2005.

KRISTEN L. BILLIAR (2002)
Professor, Biomedical Engineering, and Head of Department
B.S., Cornell University, 1991;
M.S., University of Pennsylvania, 1992; Ph.D., 1998.

STEPHEN J. BITAR (1994)
Instructor, Electrical and Computer Engineering
B.S., Worcester Polytechnic Institute, 1985; M.S., 1995.

MARCEL Y. BLAIS (2005)
Associate Teaching Professor, Mathematical Sciences
B.S., Fairfield University, 1999;
Special Masters, Cornell University, 2003; Ph.D., 2006.

JOHN J. BLANDINO (2001)
Associate Professor, Mechanical Engineering
B.S., Rensselaer Polytechnic Institute, 1987;
M.S., Massachusetts Institute of Technology, 1989;
Ph.D., California Institute of Technology, 2001.

YEVGENIY BOGDANOV (2002)
Assistant Teaching Professor, Electrical and Computer Engineering
B.S., Worcester Polytechnic Institute, 1997; M.S., 1998;
Ph.D., 2002.

ESTHER F. BOUCHER-YIP (2012)
Associate Teaching Professor, Humanities and Arts
B.A., University of Malaya, 1994; Dip.Ed.(TESL), 1995;
M.Phil., University of Cambridge, 1999;
Ed.D., University of Leicester, 2005.

KRISTIN BOUDREAU (2009)
Professor, Humanities and Arts
B.A., Cornell University, 1987;
M.A., University of Rochester, 1989; Ph.D., 1992.

MOHAMED BRAHIMI (2016)
Instructor/Lecturer, Humanities and Arts
B.A., Communication, Suffolk University, 2007;
M.S., Political Science, Suffolk University, 2008.

JOEL J. BRATTIN (1990)
Professor, Humanities and Arts
A.B., University of Michigan, 1978;
Ph.D., Stanford University, 1985.

ULRIKE BRISSON (2006)
Associate Teaching Professor, Humanities and Arts
B.S., University of Hannover-Germany;
M.A., The Pennsylvania State University, 1995; Ph.D., 2000.

DREW R. BRODEUR (2010)
Associate Teaching Professor, Chemistry and Biochemistry
B.S., University of Rhode Island (URI), 2006;
B.A., 2006; Ph.D., 2011.

CHRISTOPHER A. BROWN (1989)
Professor, Mechanical Engineering
B.A., University of Vermont, 1975;
M.S., 1979; Ph.D., 1983.

DAVID C. BROWN (1980)
Professor, Computer Science; Professor, Mechanical Engineering
B.S., North Staffordshire Polytechnic, 1970;
M.S., University of Kent at Canterbury, 1974;
M.S., Ohio State University, Columbus,1976; Ph.D., 1984.

DONALD R. BROWN (2000)
Interim Department Head of Electrical and Computer Engineering
Associate Professor, Electrical and Computer Engineering
B.S., University of Connecticut, 1992; M.S., 1996;
Ph.D., Cornell University, 2000.

CRYSTAL BROWN (2019)
Assistant Teaching Professor, Social Sciences and Policies Studies
B.S., Pennsylvania State University, 2006;
M.S., Ph.D., University of Oregon, 2016, 2019.

FLOYD BROWNEWELL (2019)
Professor of Practice, Biology and Biotechnology
B.S., Slippery Rock University, Pennsylvania, 1988;
B.S., M.A., Johnson State College, Vermont, 1994
Ph.D., University of Vermont, 2000;

MICHAEL A. BUCKHOLT (2001)
Associate Teaching Professor, Biology and Biotechnology
B.S., The Pennsylvania State University, 1987;
Ph.D., Worcester Polytechnic Institute, 1992.

STEVEN C. BULLOCK (1989)
Professor, Humanities and Arts
B.A., Houghton College, 1978;
M.A., SUNY-Binghamton, 1980;
A.M., Brown University, 1982; Ph.D., 1986.

SHAWN C. BURDETTE (2011)
Associate Professor, Chemistry and Biochemistry
B.S., Case Western Reserve University, 1997;
Ph.D., Massachusetts Institute of Technology, 2002.

NANCY A. BURNHAM (2000)
Professor, Physics
B.A., Colgate University, 1980;
M.S., University of Colorado, Boulder, 1985; Ph.D., 1987.

BRUCE E. BURSTEN (2015)
Professor, Chemical Engineering
S.B., University of Chicago, 1974;
Ph.D., University of Wisconsin, Madison, 1978.

TIFFINY A. BUTLER (2015)
Assistant Teaching Professor, Mechanical Engineering
B.S., Eastern University, 2007;
M.S., Temple University, 2009; Ph.D., 2014.

BERK ÇALLI (2018)
Visiting Assistant Professor, Computer Science/Robotics Engineering
B.S., M.S., Sabanci University, 2006, 2008;
Ph.D., Delft University of Technology, the Netherlands, 2015.

TERRI ANNE CAMESANO (2000)
Dean of Graduate Studies;
Professor, Chemical Engineering
B.S., University of Rochester, 1995;
M.S., University of Arizona, 1997;
Ph.D., Pennsylvania State University, 2000.

LUCA CAPOGNA (2013)
Professor, Mathematical Sciences, and Head of Department
B.S., University of Rome II (Tor Vergata), 1990;
Ph.D., Purdue University, 1996.

FABIO CARRERA (1991)
Teaching Professor
B.S., Worcester Polytechnic Institute, 1984; M.S., 1996;
Ph.D., Massachusetts Institute of Technology, 2004.

FARLEY CHERY (2016)
Assistant Teaching Professor, Interactive Media and Game Development
B.F.A., Collins College, 2005;
M.F.A., Full Sail University, 2010.

JAMES CHIARELLI (2012)
Instructor/Lecturer, Interdisciplinary and Global Studies
B.A., Boston University;
M.A., University of Missouri-Columbia;

KENNY CHING (2019)
Assistant Professor, Foisie Business School
B.Sc., John Hopkins University, 2003;
S.M., Ph.D., Massachusetts Institute of Technology, 2013, 2015.

PETER R. CHRISTOPHER (1963)
Professor, Mathematical Sciences
A.B., Clark University, 1959; M.A., 1963; Ph.D., 1982.

EDWARD A. CLANCY (2000)
Professor, Electrical and Computer Engineering
B.S., Worcester Polytechnic Institute, 1983;
M.S., Massachusetts Institute of Technology, 1987; Ph.D., 1991.

ANDREW CLARK (2015)
Assistant Professor, Electrical and Computer Engineering
B.S., University of Michigan, Ann Arbor, 2007; M.S., 2008
Ph.D., University of Washington, Seattle, 2014.

CONSTANCE A. CLARK (2006)
Associate Professor, Humanities and Arts
B.S., State University of New York/Stony Brook, 1978;
M.A., University of Colorado/Boulder, 1996; Ph.D., 2002.

WILLIAM M. CLARK (1986)
Associate Professor, Chemical Engineering
B.S., Clemson University, 1979;
Ph.D., Rice University, 1984.

MARK L. CLAYPOOL (1998)
Professor, Computer Science
B.A., Colorado College, 1990;
M.S., University of Minnesota, 1993; Ph.D., 1996.

JEANNINE M. COBURN (2016)
Assistant Professor, Biomedical Engineering
B.S, University of Massachusetts, Amherst, 2006;
Ph.D., Johns Hopkins University, 2012.

JAMES M. COCOLA (2009)
Associate Professor, Humanities and Arts
A.B., Harvard College, 1998;
Ph.D., University of Virginia, 2009.

DANIELLE COTE (2015)
Assistant Professor, Mechanical Engineering
B.S., Worcester Polytechnic Institute, 2005; M.S., 2010;
Ph.D., 2014.

RAGHVENDRA V. COWLAGI (2013)
Associate Professor, Mechanical Engineering
B.E., University of Mumbai, India, 2003;
Indian Institute of Technology Bombay, Mumbai, India, 2005;
Ph.D., Georgia Institute of Technology, Atlanta, 2011.

PATRICK H. CROWE (2019)
Instructor/Lecturer, Humanities and Arts
B.S., in Mechanical Eng. and Humanities & Arts/Drama,
Worcester Polytechnic Institute, 2011.

JOSEPH F. CULLON (2013)
Associate Teaching Professor, Humanities and Arts
B.S., Cornell University, 1991;
M.S., University of Wisconsin, Madison, 1995; M.A., 1998;
Ph.D., 2003.

JOSHUA CUNEO (2017)
Instructor, Computer Science
B.S., Georgia Institute of Technology, 2008; M.S., 2010.

BLAKE H. CURRIER (2013)
Assistant Teaching Professor, Physics
B.S., Worcester Polytechnic Institute; Ph.D., 2013.

ROBERT DANIELLO (2015)
Assistant Teaching Professor, Mechanical Engineering
B.B., University of Massachusetts, Amherst, 2006; M.S., 2009;
Ph.D. 2013.

ALTHEA DANIELSKI (2016)
Assistant Teaching Professor, Humanities and Arts
B.A., Wesleyan University, 1992;
M.A., SIT Graduate Institute, 2004;
A.B.E. University of Minnesota, 2009.

RAVINDRA DATTA (1998)
Professor, Chemical Engineering
B.T., Indian Institute of Technology (India), 1972;
Ph.D., University of California, Santa Barbara, 1981.

JOHN-MICHAEL DAVIS (2019)
Assistant Teaching Professor, Interdisciplinary and Global Studies
B.A., Wilfrid Laurier University, 2009;
M.Sc., McGill University, 2012;
M.A., Ben Gurion University, 2013;
Ph.D., Memorial University of Newfoundland, 2017.

LINDSAY G. DAVIS (2018)
Assistant Teaching Professor, Humanities and Arts
B.A., University of Vermont, 2005
M.A., Dartmouth College, 2009;
Ph.D., the George Washington University, 2018.

COREY DEHNER (2012)
Associate Teaching Professor, IGSD
Ph.D., Northeastern University, 2009.

NICHOLAS A. DEMBSEY (1995)
Professor, Fire Protection Engineering
B.S., University of Michigan, Ann Arbor, 1986
M.S., University of California at Berkeley, 1988; Ph.D., 1995.

MICHAEL A. DEMETRIOU (1997)
Professor, Mechanical Engineering
B.S., University of Southern California, 1987; M.S., 1989;
M.S., 1990; Ph.D., 1993.

CHRYSANTHE DEMETRY (1993)
Associate Professor, Mechanical Engineering;
Director, Morgan Teaching and Learning Center
B.S., Worcester Polytechnic Institute, 1988;
Ph.D., Massachusetts Institute of Technology, 1993.

ROBERT E. DEMPSKI (2009)
Associate Professor, Chemistry and Biochemistry
B.S., Bucknell University, 1997;
Ph.D., Massachusetts Institute of Technology, 2003.

N. AARON DESKINS (2009)
Associate Professor, Chemical Engineering
B.S., University of Utah, 2001;
Ph.D., Purdue University, 2006.

LORENZO DE CARLI (2018)
Assistant Professor, Computer Science
B.Sc., Politecnico di Torino. Italy, 2005;
M.Sc., Politecnico di Torino. Italy, 2007.
Ph.D., University of Wisconsin, Madison, 2016.

JENNIFER DEWINTER (2009)
Professor and Associate Head of Department, Humanities and Arts
B.A., Eastern Washington University, 2000; M.A., 2002;
Ph.D., University of Arizona, 2008.

DAVID DIBIASIO (1980)
Associate Professor, Chemical Engineering
B.S., Purdue University, 1972; M.S., 1977; Ph.D., 1980.

FRANK A. DICK (2007)
Associate Teaching Professor, Physics
B.S., University of Texas/San Antonio, 1984;
M. S., Worcester Polytechnic Institute, 2005; Ph.D., 2007.

DANIEL A. DIMASSA (2014)
Assistant Professor, Humanities and Arts
B.A., University of Notre Dame, 2006;
M.A.R., Yale Divinity School, 2008
M.A., University of Pennsylvania, 2010; Ph.D., 2014.

MIKHAIL F. DIMENTBERG (1994)
Professor, Mechanical Engineering
M.S.C., Moscow Institute of Power Engineering, 1958;
Ph.D., 1963; Doctor of Technical Sciences, 1971.

JAMES P. DITTAMI (1985)
Professor, Chemistry and Biochemistry
A.B., College of The Holy Cross, 1975;
M.S., Boston College, 1978;
Ph.D., Rensselaer Polytechnic Institute, 1983.

ANTHONY G. DIXON (1980)
Professor, Chemical Engineering
B.S., Edinburgh University, 1975; Ph.D., 1978.

SOUSSAN DJAMASBI (2004)
Professor, Foisie Business School
B.S., Christian Albert University (Germany), 1988;
M.S., University of New Mexico, Albuquerque, 1991;
Ph.D., University of Hawaii, Manoa, 2004.

LESLIE DODSON (2016)
Assistant Teaching Professor, Undergraduate Studies
B.A., Lake Forest College;
M.S., Journalism, Northwestern University;
Ph.D., Technology, Media & Society, University of Colorado, Boulder.

JOSEPH DOIRON (2019)
Assistant Teaching Professor, Interdisciplinary and Global Studies
B.A., Xavier University, 2002;
M.A., Tufts University, 2005;
Ph.D., Boston University, 2017.

TANJA DOMINKO (2006)
Associate Professor, Biology and Biotechnology
DVM, University of Ljubljana (Slovenia), 1985; M.S., 1986;
Ph.D., University of Wisconsin - Madison, 1996.

YARKIN DOROZ (2018)
Assistant Teaching Professor, Computer and Electrical Engineering
B.S., M.S., Sabanci University, Istanbul, 2009, 2011;
Ph.D., Worcester Polytechnic Institute, 2017.

DANIEL J. DOUGHERTY (2002)
Professor, Computer Science
B.A., University of Maryland, 1974; Ph.D., 1982.

EMILY M. DOUGLAS (2017)
Professor, Social Science and Policy Studies, and Head of Department
B.A., Clark University, 1995
M.S., University of Massachusetts, 1999; Ph.D., 2002.

JAMES K. DOYLE (1992)
Associate Professor, Social Science and Policy Studies
B.A., University of California/Berkley, 1982;
M.A., University of Colorado/Boulder, 1990; Ph.D., 1991.

TATIANA DOYTCHINOVA (2012)
Senior Instructor, Mathematical Sciences
B.S., M.S., Mathematics, Moscow State University, 1987;
M.S., Applied Mathematics, Carnegie Mellon University, 1999;
M.S., Applied Statistics, Worcester Polytechnic Institute, 2001.

HOLGER DROESSLER (2019)
Assistant Professor, Humanities and Arts
M.A., Ludwig-Maximilians University, 2008;
A.M., History, Ph.D., Harvard University, 2011;2015.

WEN-HUA DU (2017)
Assistant Teaching Professor, Associate Director of the China Hub, Humanities and Arts Department
B.A., Soochow University, Taiwan;
M.A., National Taiwan Normal University, Taiwan;
Ph.D., University of Wisconsin.

R. JAMES DUCKWORTH (1987)
Associate Professor, Electrical and Computer Engineering
B. Eng., Bradford University, 1981;
Ph.D., Nottingham University, 1984.

JEANINE D. DUDLE (2017)
Associate Professor, Civil and Environmental Engineering;
B.S., Cornell University, 1993;
M.S., University of Massachusetts/Amherst, 1995; Ph.D., 1999.

JOSEPH B. DUFFY (2006)
Associate Professor, Biology and Biotechnology, and Head of Department
B.S., Cornell University, 1987;
Ph.D., University of Texas, 1992.

BETHEL L. EDDY (2007)
Associate Professor, Humanities and Arts
B.S., Northeast Louisiana University, 1978;
M.A., University of North Carolina/Greensboro, 1992;
M.A., Princeton University, 1995; Ph.D., 1998.

CARRICK EGGLESTON (2019)
Professor, Civil and Environmental Engineering, and Head of Department
A.B., Dartmouth College, Hanover, NH, 1983;
Ph.D., Stanford University, 1991.

LAUREEN ELGERT (2011)
Associate Professor, Social Science and Policy Studies
B.A., Trent University, 1999;
M.Sc., University of Alberta, Edmonton, 2003;
Ph.D., London School of Economics, 2011.

MOHAMMED EL HAMZAOUI (2018)
Instructor, Humanities and Arts
B.A., Sidi Mohamed Ben Abdullah University, Morocco, 2009;
M.A., 2011.

TAHAR EL-KORCHI (1987)
Professor, Civil and Environmental Engineering
B.S., University of New Hampshire, 1980;
M.S., 1982; Ph.D., 1986.

MICHAEL B. ELMES (1990)
Professor, Foisie Business School
B.S., Union College, 1975;
M.A., Colgate University, 1979;
Ph.D., Syracuse University, 1989.

MOHAMED Y. ELTABAKH (2011)
Associate Professor, Computer Science
B.S., Alexandria University (Egypt), 1999; M.S., 2001;
M.S., Purdue University, 2005; Ph.D., 2010.

FATEMEH EMDAD (2015)
Associate Teaching Professor, Data Sciences
B.Sc., Shiraz University, Shiraz, 1992;
M.Sc., Tehran Tarbiat Moallem University, Tehran, 1995;
M.Sc., Colorado State University, 2002; Ph.D., 2007.

MARION H. EMMERT (2011)
Associate Professor, Chemistry and Biochemistry
Diploma, Albert-Ludwigs-Universitat Freiburg, Germany, 2004;
Ph.D., Westfälische Wilhelms-Universität Münster, Germany, 2009.

MICHAEL ENGLING (2019)
Assistant Teaching Professor, Computer Science
B.S., University of Tampa, 1986;
M.S., Lehigh University, 1989;
M.S., Ph.D., Stevens Institute of Technology, 2014, 2017.

MICHELLE EPHRAIM (1999)
Associate Professor, Humanities and Arts
B.A., Tufts University, 1991;
M.A., University of Wisconsin, Madison, 1993; Ph.D., 1998.

BRENTON D. FABER (2011)
Professor, Humanities and Arts
B.A., University of Waterloo, 1992;
M.A., Simon Fraser University, 1993;
Ph.D., University of Utah, 1998.

NATALIE G. FARNY (2013)
Assistant Professor, Biology and Biotechnology
B.S., Boston College, 2000;
Ph.D., Harvard University, 2009.

MOHAMAD FARZIN MOGHADAM (2017)
Assistant Teaching Professor, Civil and Environmental Engineering
B.A., Shahid Beheshti University, Tehran, Iran, 2006;
M.S., Tarbiat Modares University, Tehran, Iran, 2009;
M.Arch., University of Amherst, 2013; Ph.D., 2017.

JOSEPH D. FEHRIBACH (1992)
Associate Professor, Mathematical Sciences
B.A., Centre College, 1980;
M.A., Duke University 1982; Ph.D., 1985.

GREGORY S. FISCHER (2008)
Professor, Mechanical Engineering
B.S., Rensselaer Polytechnic Institute, 2002;
M.S.E., Johns Hopkins University, 2003; Ph.D., 2008.

MUSTAPHA S. FOFANA (1997)
Associate Professor, Mechanical Engineering
B.S./M.S., Budapest Technical University, 1986;
M.A.S., University of Waterloo, 1989; Ph.D., 1993.

KATHERINE FOO (2017)
Assistant Teaching Professor, Interdisciplinary and Global Studies
B.A., Williams College, 2002;
M.S./M.L.A., University of Michigan, 2008;
Ph.D., Clark University, 2015.

JIE FU (2015)
Assistant Professor, Robotics Engineering
B.S., Beijing Institute of Technology, 2007; M.S., 2009;
Ph.D., University of Delaware, 2013.

COSME FURLONG-VAZQUEZ (1999)
Professor, Mechanical Engineering
B.Eng., University of the Americas, 1989;
M.S., Worcester Polytechnic Institute, 1992; Ph.D., 1999.

JOHN S. GALANTE (2016)
Assistant Teaching Professor, Humanities and Arts
B.S., Tufts University, 2000;
M.A., Columbia University, 2008;
Ph.D., University of Pittsburgh, 2016

THOMAS GANNON (1991)
Professor of Practice, Electrical and Computer Engineering
B.S., Illinois Institute of Technology, 1970;
M.S., Purdue University, 1971;
Ph.D., Stevens Institute of Technology, 1977.

NIKOLAOS A. GATSONIS (1994)
Professor, Mechanical Engineering;
Director, Aerospace Engineering Program
B.S., Aristotelian University of Thessaloniki, 1983;
M.S., University Michigan, 1986;
M.S., Massachusetts Institute of Technology, 1987;
Ph.D., 1991.

GLENN R. GAUDETTE (2006)
Professor, Biomedical Engineering
B.S., University of Massachusetts/Dartmouth, 1989;
M.S., Georgia Institute of Technology, 1992;
Ph.D., State University of New York/Stony Brook, 2002.

MICHAEL A. GENNERT (1987)
Professor, Computer Science;
S.M.E.E., S.B.C.S., S.B.E.E., Massachusetts Institute of Technology, 1980; Sc.D., 1987.

ARNE GERICKE (2011)
Professor, Chemistry and Biochemistry, and Head of Department;
John C. Metzger, Jr. Professor in Chemistry
B.S., University of Hamburg (Germany), 1988; Dr. rev. nat., 1994.

DESPOINA GIAPOUDZI (2018)
Visiting Instructor, Humanities and Arts
B.S., Worcester Polytechnic Institute, 2016.

DOMINIC GOLDING (2007)
Teaching Professor, IGSD
B.A., Exeter College, 1981;
M.A., Clark University, 1986; Ph.D., 1988.

EDWARD GONSALVES (1996)
Instructor, Foisie Business School
B.S., M.S., Worcester Polytechnic Institute, 1981; 1994.

ADRYEN GONZALEZ (2018)
Instructor, Humanities ad Arts
B.F.A., California College of the Arts, 2016.

ROGER S. GOTTLIEB (1981)
Professor, Humanities and Arts
B.A., Brandeis University, 1968; Ph.D., 1975.

JOHN GOULET (1993)
Teaching Professor, Mathematical Sciences
B.S., Worcester Polytechnic Institute, 1973;
M.S., Rensselaer Polytechnic Institute, 1974; Ph.D., 1976.

RONALD GRIMM (2014)
Assistant Professor, Chemistry and Biochemistry
B.S., Case Western Reserve University, 1999;
Ph.D., California Institute of Technology, 2005.

SELCUK I. GUCERI (2011)
Professor, Mechanical Engineering
B.S., M.S., Middle East Technical University, 1960;
Ph.D., North Carolina State University, 1976.

ULKUHAN GULER (2018)
Visiting Assistant Professor, Electrical and Computer Engineering
B.Sc., Istanbul Technical University, Turkey, 1999;
M.Sc., the University of Tokyo, Japan, 2003
Ph.D., Bogazici University, Turkey, 2014.

TIAN GUO (2016)
Assistant Professor, Computer Science
B.Eng., Nanjing University, China, 2010;
M.S, Ph.D., University of Massachusetts, Amherst, 2013, 2016.

EDWARD R. GUTIERREZ (2016)
Assistant Professor, Humanities and Arts/IMGD
B.A., California Institute of the Arts, Valencia, 1983;
M.A, Academy of Art University, San Francisco, 2007.

ADRIENNE HALL-PHILLIPS (2011)
Associate Professor, Foisie Business School
Faculty Program Director, B.S. in Business and B.S. in Management Engineering
B.S., North Carolina AT&T State University, 2000;
M.S. Purdue University, 2008; Ph.D., 2011.

MARGARITA HALPINE (2006)
Assistant Teaching Professor, Humanities and Arts
B.A., College of New Rochelle, 1976;
M.A., Columbia University, 1980; M. Ph., 1984;
Ph.D., University of Connecticut, 1995.

JAMES P. HANLAN (1975)
Professor of History, Humanities and Arts
A.B., College of the Holy Cross, 1967;
M.A., Clark University, 1971; Ph.D., 1979.

PETER H. HANSEN (1992)
Professor, Humanities and Arts;
Director, International and Global Studies
B.A., Carleton College, 1984;
M.A., Harvard University, 1986; Ph.D., 1991.

JOSHUA HARMON (2013)
Associate Teaching Professor, Humanities and Arts
B.A., Marlboro College, 1994;
M.A., Cornell University, 1997.

LANE HARRISON (2015)
Assistant Professor, Computer Science
B.S., UNC-Charlotte, 2009; Ph.D., 2013.

NEIL T. HEFFERNAN (2002)
Professor, Computer Science
B.A., Amherst College, 1993;
M.S., Carnegie Mellon University, 1998; Ph.D., 2001.

DESTIN HEILMAN (2006)
Associate Teaching Professor, Chemistry and Biochemistry
B.S., The Pennsylvania State University, 2000;
Ph.D., University of Massachusetts Medical School, 2006.

GEORGE T. HEINEMAN (1996)
Associate Professor, Computer Science
B.A., Dartmouth College, 1989;
M.S., Columbia University, 1990; Ph.D., 1996.

ARTHUR C. HEINRICHER, JR. (1992)
Dean of Undergraduate Studies;
Professor, Mathematical Sciences
B.S., University of Missouri/St. Louis, 1980;
Ph.D., Carnegie Mellon University, 1986.

LTC ADAM D. HEPPE (2018)
Department Head for Army ROTC
B.S., Engineering Management, West Point, 2002;
M.B.A., Webster University, 2014.

ROBERT HERSH (2004)
Instructor, IGSD
B.A., University of Sussex, Brighton, England,1978;
M.A., University of Michigan, Ann Arbor, 1984;
Certification, United Nations Environmental Programme, 1991;
M.A., Tufts University, 1992.

HUONG NGO HIGGINS (1998)
Professor, Foisie Business School
B.A., (French), University of Ho Chi Minh City, 1990;
B.A., (English), 1990;
M.A., Georgia State University, 1996; Ph.D., 1998.

LORRAINE D. HIGGINS (2003)
Teaching Professor, Humanities and Arts;
Director of Communication Across the Curriculum
B.A., Carnegie Mellon University, 1985; M.A., 1991;
Ph.D., 1992.

ZHIKUN HOU (1991)
Professor, Mechanical Engineering
B.S., Fudan University, 1974;
M.S., Tongji University, 1981;
M.S., California Institute of Technology, 1986; Ph.D., 1990.

FRANK HOY (2009)
Professor, Foisie Business School
Director, Collaborative for Entrepreneurship and Innovation;
Paul Beswick Professorship of Innovation and Entrepreneurship
B.B.A., University of Texas at El Paso, 1967;
M.B.A., University of North Texas, 1970;
Ph.D., Texas A&M University, 1979.

XIN-MING HUANG (2006)
Professor, Electrical and Computer Engineering
B.S., Northwestern Polytechnic University (China), 1994;
M.Eng., 1996;
Ph.D., Virgina Polytechnic Institute and State University, 2001.

MAYER HUMI (1971)
Professor, Mathematical Sciences
B.S., Hebrew University of Jerusalem, 1963; M.S., 1964;
Ph.D., Weizmann Institute of Science, 1969.

GERMANO S. IANNACCHIONE (1998)
Professor, Physics
B.S., University of Akron, 1987; M.S., 1990;
Ph.D., Kent State University, 1993.

JAGANNATH JAYACHANDRAN (2018)
Assistant Professor, Mechanical Engineering
B.S., Vellore Institute of Technology, India, 2007;
M.S., Ph.D., University of Southern California, 2013; 2016.

SONGBAI JI (2016)
Associate Professor, Biomedical Engineering
B.S., M.S., Shanghai Jiatong University, China 1996, 1999;
M.S., D.Sc., Washington University in St. Louis, 2003.

J. SCOTT JIUSTO (2004)
Associate Professor, Interdisciplinary and Global Studies Division
B.S., Empire State College (SUNY), 1992;
M.A., University of Albany (SUNY), 1998;
Ph.D., Clark University, 2004.

MICHAEL JOHNSON (2003)
Associate Teaching Professor, Mathematical Sciences
B.S. Worcester State College, 1997; B.S., 1998;
M.S., Worcester Polytechnic Institute, 2001.

SHARON A. JOHNSON (1988)
Professor, Foisie Business School
Area Head (Operations and Industrial Engineering)
B.S., University of Michigan, 1983;
M.S., Cornell University, 1986; Ph.D., 1989.

SNEHALATA KADAM (2014)
Assistant Teaching Professor, Physics
B.Sc., Shivaji University, Kolhapur, India, 1994; M.Sc., 1996;
Ph.D., University of Tuebingen, Germany, 2003.

RUDRA KAFLE (2015)
Assistant Teaching Professor, Physics
B.S. Tribhuvan University, Kathmandu, Nepal, 1992; M.S., 1996;
M.S, Worcester Polytechnic Institute, 2007; Ph.D., 2012.

GEORGE A. KAMINSKI (2008)
Associate Professor, Chemistry and Biochemistry
B.S./M.S., Moscow Institute of Physics and Technology, 1990;
M.S., Yale University, 1993; Ph.D., 1998.

NIKHIL KARANJGAOKAR (2015)
Assistant Professor, Mechanical Engineering
B.Tech., National Institute of Technology, Calicut, 2006;
M.S, Carnegie Mellon University, 2007;
Ph.D., University of Illinois at Urbana-Champaign, 2013.

HEKTOR KASHURI (2008)
Assistant Teaching Professor, Physics
B.S., University of Tirana (Albania), 1997;
ICTP Diploma, The Abdus Salam ICTP (Italy), 2000;
Ph.D., Northeastern University, 2008.

NIKOLAOS KAZANTZIS (2001)
Professor, Chemical Engineering
B.S., University of Theseloniki (Greece), 1990;
M.S., University of Michigan, 1992; M.S.E., 1993;
Ph.D., 1997.

MARIE KELLER (2006)
Assistant Teaching Professor, Humanities and Arts
B.F.A., Rhode Island School of Design, 1994;
M.F.A., New York Academy of Art, 1996.

JEAN KING (2017)
Peterson Family Dean of Arts and Sciences;
Professor of Biology and Biotechnology
B.S., St. Francis College, Brooklyn 1979;
M.S., City University of New York 1982;
Ph.D., New York University 1988.

PAUL E. KIRBY (2015)
Instructor, Humanities and Arts
B.A., Assumption College, 1966;
B.Ph., Laval University, 1967;
Grad-non-degree student In Philosophy, UMASS, 1970;

STEVEN KMIOTEK (2012)
Professor of Practice, Chemical Engineering
Ph.D., Worcester Polytechnic Institute, 1986.

XIANGNAN KONG (2014)
Assistant Professor, Computer Science and Data Science
B.S., Nanjing University, Nanjing, China, 2006; M.A., 2009;
Ph.D., University of Illinois at Chicago, 2014.

RENATA KONRAD (2009)
Associate Professor, Foisie Business School
B.A.S., University of Toronto, 1999; M.A.S., 2004;
Ph.D., Purdue University, 2009.

JANICE KOOKEN (2019)
Assistant Research Professor, Social Science and Policy Studies
B.S., Queens College of the City of New York, 1982;
M.S., University of Illinois at Chicago, 1998;
Ph.D., University of Connecticut, 2015.

NIMA KORDZADEH (2017)
Assistant Professor, Foisie Business School
B.S., Sharif University of Technology, Tehran, Iran, 2006;
M.B.A., 2009;
Ph.D., University of Texas at San Antonio, 2014.

DMITRY A. KORKIN (2014)
Associate Professor, Computer Science
B.Sc., Moscow State University, Moscow, Russia, 1997;
M.Sc., Moscow State University, Moscow, Russia, 1999;
Ph.D., University of New Brunswick, NB, Canada, 2003.

J. ROBERT KRUEGER (2004)
Associate Professor, Social Science and Policy Studies
B.S., Oklahoma State University, 1991;
M.S.L., Vermont Law School, 1992;
M.A., Clark University, 1998; Ph.D., 2004.

UMA T. KUMAR (1996)
Associate Teaching Professor, Chemistry and Biochemistry
Ph.D., University of Cincinnati, 1993.

COURTNEY KURLANSKA (2017)
Assistant Teaching Professor, Interdisciplinary and Global Studies
B.A., Brandeis University, 1999;
M.S., University of New Orleans, 2005;
Ph.D., State University of New York, Albany, 2012.

DIANA A. LADOS (2006)
Professor, Mechanical Engineering
B.S./M.S., Polytechnic University of Bucharest, 1997;
M.S., Southern Illinois University, 1999;
Ph.D., Worcester Polytechnic Institute, 2004.

CHRISTOPHER R. LAMBERT (2001)
Associate Teaching Professor, Bioengineering Institute
B.S., University College (Wales), 1979;
Ph.D., University of Paisley (Scotland), 1983.

ADAM C. LAMMERT (2019)
Assistant Professor, Biomedical Engineering
B.A., Vassar College, 2004;
M.S., North Carolina State University, 2006;
Ph.D., University of Southern California, 2014.

CHRISTOPHER J. LARSEN (1996)
Professor, Mathematical Sciences
B.S., Carnegie Mellon University, 1989;
J.D., University of Maryland School of Law, 1992;
M.S., Carnegie Mellon University, 1994; Ph.D., 1996.

KWONMOO LEE (2014)
Assistant Professor, Biomedical Engineering
B.S., Pohang University of Science and Technology, South Korea, 1996; M.S., 1998;
Ph.D., Massachusetts Institute of Technology, 2010.

KYUMIN LEE (2014)
Assistant Professor, Computer Science
B.S., Kyonggi University, South Korea, 2005;
M.S., Sungkyunkwan University, South Korea, 2007;
Ph.D., Texas A & M University, 2013.

SUZANNE LEPAGE (2007)
Instructor, Civil Engineering
B.S. Worcester Polytechnic Institute, 1995; M.S., 2010.

SHANA LESSING (2019)
Assistant Teaching Professor, Humanities and Arts
B.A., Sarah Lawrence College, 2002;
M.A., Columbia University, 2007;
Ph.D., City University of New York, expected November 2019.

FIONA LEVEY (2013)
Associate Teaching Professor, Mechanical Engineering
B.Sc., University of Witwatersrand, South Africa, 1992;
Ph.D., 2001.

GREGORY LEWIN (2019)
Assistant Teaching Professor, Mechanical Engineering
B.A., Carleton College, 1990
M.S., University of Virginia, 1999;
Ph.D., University of Virginia2003.

KEVIN LEWIS (2017)
Professor of Practice, Humanities and Arts
B.S., Worcester State University, 1992;
M.A., Northeastern University, 1998;

YANHUA LI (2015)
Assistant Professor, Computer Science
B.E., Sichuan University, Chengdu, China, 2003; M.Sc, 2006;
Ph.D., Beijing University, China, 2009.
Ph.D., University of Minnesota, 2013.

ZHI (JANE) LI (2017)
Assistant Professor, Mechanical Engineering
B.S., China Agricultural University, China, 2006;
M.Sc., University of Victoria, BC, Canada, 2009;
Ph.D., University of California, Santa Cruz, 2014.

JIANYU LIANG (2004)
Professor, Mechanical Engineering
B.S., Central South University (China), 1995; M.E., 1998;
Ph.D., Brown University, 2004.

SIMONA LIGUORI (2018)
Assistant Research Professor, Chemical Engineering
M.S., Calabria University, Italy, 2008; Ph.D., 2011.

SHICHAO LIU (2018)
Assistant Professor, Civil and Environmental Engineering
B. Eng., M. Eng., Tianjin University, China, 2009;
Ph.D., University of Texas at Austin, 2014.

YUXIANG LIU (2013)
Assistant Professor, Mechanical Engineering
B.S., University of Science and Technology of China, Hefei, Anhui, China, 2002; M.S., 2005;
Ph.D., University of Maryland, College Park, 2011.

ELEANOR T. LOIACONO (2000)
Professor, Foisie Business School
B.A., Boston University, 1992;
M.B.A., Boston College, 1996;
Ph.D., University of Georgia, 2000.

ELIZABETH LONG LINGO (2015)
Assistant Professor, Foisie Business School
B.A., University of Massachusetts, Amherst, 1993;
A.M., Harvard University, 2002; Ph.D., 2005.

FRED J. LOOFT (1980)
Professor, Electrical and Computer Engineering;
Academic Director of Systems Engineering
B.S., University of Michigan, 1973; M.S., 1974, 1976;
Ph.D., 1979.

REINHOLD LUDWIG (1986)
Professor, Electrical and Computer Engineering
Diplom-Ingenieur, University of Wuppertal (West Germany), 1983;
Ph.D., Colorado State University, 1986.

ROGER YIN-MAN LUI (1983)
Professor, Mathematical Sciences
B.S., University of Minnesota, 1975; Ph.D., l981.

KONSTANTIN A. LURIE (1989)
Professor, Mathematical Sciences
M.Sc., Leningrad Polytechnical Institute (USSR), 1959;
Ph.D., A.F. Ioffe Physical-Technical Institute, Academy of Sciences (USSR), 1964; D.Sc., 1972.

JOHN C. MACDONALD (2001)
Associate Professor, Chemistry
B.A., Bowdoin College, 1987;
Ph.D., University of Minnesota, 1993.

AARTI S. MADAN (2010)
Associate Professor, Humanities and Arts
B.A., Birmingham-Southern College, 2004;
M.A., University of Pittsburgh, 2007; Ph.D., 2010.

RYAN S. MADAN (2011)
Associate Teaching Professor, Humanities and Arts;
Director, Writing Center
B.A., University of California, Los Angeles, 2002;
Ph.D., University of Pittsburgh, 2013.

YOUSEF MAHMOUD (2016)
Assistant Professor, Electrical and Computer Engineering
B.Sc., Al-Balqaa University, Jordan, 2009;
M.Sc., Masdar Institute of Science and Technology, Abu-Dhabi, UAE, 2012;
Ph.D., University of Waterloo, ON, Canada, 2016.

SERGEY N. MAKAROV (2000)
Professor, Electrical and Computer Engineering
M.S., St. Petersburg State University (Russia), 1982;
Ph.D., 1986.

MAKHLOUF M. MAKHLOUF (1989)
Professor, Mechanical Engineering;
Director, Aluminum Casting Research Laboratory
B.S., American University (Cairo), 1978;
M.S., New Mexico State University, 1981;
Ph.D., Worcester Polytechnic Institute, 1990.

RAJIB B. MALLICK (1998)
Professor, Civil and Environmental Engineering,
and Associate Head of Department;
Ralph H. White Family Distinguished Professorship
B.S., Jadavpur University (India), 1989;
M.S., Auburn University, 1993; Ph.D., 1997.

AMITY L. MANNING (2014)
Assistant Professor, Biology and Biotechnology
B.A., Brandeis University, 2002; B.S., 2002;
Ph.D., Geisel School of Medicine at Dartmouth, 2008.

OREN MANGOUBI (2019)
Assistant Professor, Mathematical Sciences, Data Science Program
B.S., Yale University, 2011;
Ph.D., Massachusetts Institute of Technology, 2016.

V.J. MANZO (2012)
Associate Professor, Humanities and Arts
B.A., Kean University, 2005;
M.M., New York University, 2007;
Ph.D., Temple University, 2012.

IVAN MARDILOVICH (1999)
Assistant Teaching Professor, Chemistry and Biochemistry
Ph.D., Peoples' Friendship University of Russia, 1982.

WILLIAM J. MARTIN (2000)
Professor, Mathematical Sciences
B.A., State University of New York/Potsdam, 1986;
M.A., 1986; Ph.D., University of Waterloo (Canada), 1992.

LAUREN M. MATHEWS (2003)
Associate Professor, Biology and Biotechnology
B.A., Connecticut College, 1996;
Ph.D., University of Louisiana/Lafayette, 2001.

PAUL P. MATHISEN (1993)
Associate Professor, Civil and Environmental Engineering
B.S., University of Massachusetts, 1984;
S.M., Massachusetts Institute of Technology, 1989; Ph.D., 1993.

INGRID E. MATOS-NIN (2003)
Associate Teaching Professor, Humanities and Arts
B.A., Universidad de Puerto Rico/Mayaguez, 1981;
B.A., Pontificia Universidad Católica de Puerto Rico, 1984;
M.A., 1988; B.S., 1997;
Ph.D., Boston University, 2004.

ANITA E. MATTSON (2016)
Associate Professor, Chemistry and Biochemistry
B.S., Northern Michigan University, 2002;
Ph.D., Northwestern University, Evanston, 2007.

CAROLYN D. MAYER (2018)
Post-Doctoral Scholar, Mathematical Sciences
B.A., Bowdoin College, 2015;
M.S., Ph.D., University of Nebraska, Lincoln, 2015, 2018.

STEPHEN MCCAULEY (2015)
Assistant Teaching Professor, Interdisciplinary and Global Studies
B.A., Loyola College, Maryland, 1996;
M.A., University of Maryland, 2001;
Ph.D., Clark University, 2009.

KATHARINE L. MCINTYRE (2018)
Assistant Professor, Humanities and Arts
B.A., Harvard University, 2004;
M..F.A., Oregon State University, 2006;
Ph.D., University of Missouri, 2013.

JOHN A. MCNEILL (1994)
Professor, Electrical and Computer Engineering, and
Interim Dean of Engineering
A.B., Dartmouth College, 1983;
M.S., University of Rochester, 1991;
Ph.D., Boston University, 1994.

JENNIFER MCWEENY (2012)
Associate Professor, Humanities and Arts
B.A., The Colorado College, 1998;
M.A., University of Hawaii, 2000;
M.A., University of Oregon, 2003; Ph.D., 2005.

DAVID MEDICH (2012)
Associate Professor, Physics, and Associate Head of Department
B. S., Union College, 1990;
M.A., State University of New York at Buffalo, 1993;
Ph.D. University of Massachusetts/Lowell, MA 1997.

YITZHAK MENDELSON (1983)
Professor, Biomedical Engineering
B.S., State University of New York at Buffalo, 1975; M.S., 1976;
Ph.D., Case Western Reserve University, 1983.

WILLIAM R. MICHALSON (1992)
Professor, Electrical and Computer Engineering
B.S. E.E., Syracuse University, 1981;
M.S., Worcester Polytechnic Institute, 1985; Ph.D., 1989.

FABIENNE MILLER (2007)
Associate Professor, Foisie Business School
Faculty Program Director, M.B.A. & M.S. in Management
M.M., Ecole de Management de Lyon, 1985;
M.P.A., Montana State University, 1998;
Ph.D., Michigan State University, 2007.

BRAJENDRA MISHRA (2015)
Kenneth G. Merriam Professor and
Associate Director of the Metals Processing Institute (MPI)
B.Tech., Indian Institute of Technology, Kharagpur, 1981;
M.S., University of Minnesota, Minneapolis, 1983; Ph.D., 1986.

JAMIE P. MONAT (2004)
Director, Executive Education;
Adjunct Assistant Professor of Management, and Professor of Practice, Corporate and Professional Education
B.S., Princeton University, 1973;
M.S., Stanford University, 1974; Ph.D., 1978.

KATHRYN M. MONCRIEF (2019)
Professor, Humanities and Arts, and Head of Department
B.A., Doane College, 1989;
M.A., University of Nebraska, 1991;
Ph.D., University of Iowa, 2000.

REBECCA A. MOODY (2018)
Assistant Teaching Professor, Humanities and Arts
B.A., Oklahoma State University, 1998;
M.A., The University of Texas at Austin, 2006;
M.A., M.Phil., Ph.D., Syracuse University, 2010; 2013; 2018;

BRIAN MORIARTY (2009)
Professor of Practice, Interactive Media and Game Development Program
B.A., Southeastern Massachusetts University, 1978;
E.Ed., Framingham State College, 2009.

UMBERTO MOSCO (2005)
Professor, Mathematical Sciences;
Harold J. Gay Chaired Professorship in Mathematics
Laurea in Mathematical Sciences, University of Rome, 1959;
Laurea in Physics, University of Rome, 1961;
Libera Docenza in Mathematical Methods in Physics, Italy, 1967.

MAQSOOD ALI MUGHAL (2018)
Assistant Teaching Professor, Electrical and Computer Engineering
B.S., Sir Syed University of Engineering and Technology, Pakistan, 2009;
M.S., Arkansas State University, 2010; M.S., 2014; Ph.D., 2015.

KÖKSAL MU (2017)
Assistant Teaching Professor, Electrical and Computer Engineering
B.Sc., Yildiz Technical University, Turkey, 2004;
M.Sc., Middle East Technical University, Turkey, 2009;
Ph.D., 2016.

BALGOBIN NANDRAM (1989)
Professor, Mathematical Sciences
B.Sc., University of Guyana, 1977, Dip. Ed., 1979;
M.Sc., University of London, Imperial College, 1981;
Ph.D., University of Iowa, 1989.

SNEHA PRABHA NARRA (2018)
Assistant Professor, Mechanical Engineering
B.E., Osmania University, India, 2012;
M.S., Carnegie Mellon University, 2013; M.E., 2015;
Ph.D., 2017.

HUSSEIN NASRALAH (2018)
Post-Doctoral Scholar, Mathematical Sciences
B.A., University of Michigan, Ann Arbor, 2012;
M.A., Ph.D., Wayne State University, Detroit, 2018.

RODICA NEAMTU (2017)
Associate Teaching Professor, Computer Science
B.Sc., University of Craiova, Romania, 1990; M.S., 1991;
Ph.D., Worcester Polytechnic Institute, 2017.

INNA NECHIPURENKO (2020)
Assistant Professor, Biology and Biotechnology
B.S., Business Administration and Biology, Bloomsburg University of Pennsylvania, 2005;
Ph.D., Case Western University, 2012.

BENJAMIN C. NEPHEW (2018)
Assistant Research Professor, Biology and Biotechnology
B.S., Hobart College, 1998;
Ph.D., Tufts University, 2003.

CHUN-KIT (BEN) NGAN (2018)
Assistant Teaching Professor, Computer Science/Data Science
B.Eng., Hong Kong University, Hong Kong, 1998;
M.B.A., California State University, 2006;
Ph.D., George Mason University, 2013.

SVETLANA NIKITINA (2004)
Associate Teaching Professor, Humanities and Arts
B.A./M.A., Moscow University (Russia), 1984; Ph.D., 1988;
Ed.M., Harvard University, 1999.

KATHY A. NOTARIANNI
Associate Professor, Fire Protection Engineering
B.S., Worcester Polytechnic Institute, 1986; M.S., 1989;
M.S., Carnegie Mellon University, 1997; Ph.D., 2000.

KAREN KASHMANIAN OATES (2010)
Professor of Biology and Biotechnology;
B.S., Rochester Institute of Technology, 1973;
Ph.D., The George Washington University, 1985.

PADRAIG O'CATHAIN (2016)
Assistant Professor, Mathematical Sciences
B.A., National University of Ireland Galway, 2007;
M. Litt., National University of Ireland Galway, 2008
Ph.D., National University of Ireland Galway, 2011.

DEAN O'DONNELL (1993)
Assistant Teaching Professor, Humanities and Arts
B.S., Worcester Polytechnic Institute, 1986;
M.F.A., Brandeis University, 1990.

DAVID J. OLINGER (1990)
Associate Professor, Mechanical Engineering
B.S., Lafayette College, 1983;
M.S., Rensselaer Polytechnic Institute, 1985;
M.S., Yale University, 1988; Ph.M., 1988; Ph.D., 1990.

XAVIER RAMOS OLIVE (2019)
Post-Doctoral Scholar, Mathematical Sciences
B.Sc., Mathematics, Polytechnic University at Catalonia, 2013;
B.SC., Physics, University of Barcelona, 2014;
Ph.D., University of California, Riverside, 2019.

CARISSA PEREZ OLSEN (2017)
Assistant Professor, Chemistry and Biochemistry
B.A. Cornell University, 2005;
Ph.D., University of Washington, Seattle, 2011.

SARAH D. OLSON (2011)
Associate Professor, Mathematical Sciences
B.A. Providence College, 2003;
M.S., University of Rhode Island, 2005;
Ph.D., North Carolina State University, 2008.

CAGDAS ONAL (2013)
Associate Professor, Mechanical Engineering
B.Sc., Sabanci University, Istanbul, Turkey, 2003; M.Sc., 2005;
Ph.D., Carnegie Mellon University, 2009.

ERIN OTTMAR (2015)
Assistant Professor, Social Sciences and Policy Studies
B.A., University of Richmond, 2005;
Ph.D., University of Virginia, 2011.

RANDY PAFFENROTH (2014)
Associate Professor, Mathematical Sciences/Data Science
B.S., Boston University, 1992;
Ph.D., University of Maryland, College Park, 1999.

RAYMOND L. PAGE (2006)
Professor of Practice, Biomedical Engineering
B.S., West Virginia University, 1987; M.S., 1989;
Ph.D., Virginia Polytechnic Institute and State University, 1993.

KAVEH PAHLAVAN (1985)
Professor, Electrical and Computer Engineering
M.S., University of Teheran, 1975;
Ph.D., Worcester Polytechnic Institute, 1979.

BALAJI PANCHAPAKESAN (2014)
Professor, Mechanical Engineering
B.S., NIT, India, 1994;
Ph.D., University of Maryland, College Park, 2001.

OLEG V. PAVLOV (2002)
Associate Professor, Social Science and Policy Studies
B.S., University of Southern California, 1994; Ph.D., 2000.

CREIGHTON PEET (2000)
Teaching Professor, Interdisciplinary and Global Studies Division
B.A., Harvard College, 1966;
P.Phil., Columbia University, 1978; Ph.D., 1978.

THELGE BUDDIKA PEIRIS (2014)
Assistant Teaching Professor, Mathematical Sciences
B.S., University of Sri Jayewardenepura, Sri Lanka, 2005;
M.S., Southern Illinois University, 2010.
Ph.D., Southern Illinois University, 2014.

DOUGLAS T. PETKIE (2016)
Professor and Department Head, Physics
B.S., Carnegie Mellon University, 1990;
Ph.D., Ohio State University, Columbus, 1996.

GEOFFREY PFEIFER (2013)
Associate Teaching Professor, Global School and Humanities and Arts
B.A., University of Colorado, 2003.
M.A., University of New Mexico, 2005;
Ph.D., University of South Florida, 2012.

CARLO PINCIROLI (2016)
Assistant Professor, Computer Science
M.S., Politecnico di Milano, Italy, 2005;
M.S., University of Illionois at Chicago, 2005;
Ph.D., Université Libre de Bruxelles, 2014.

GEORGE D. PINS (2000)
Professor, Biomedical Engineering, and Associate Head of Department
B.S., Rutgers College of Engineering, 1989;
Ph.D., Rutgers University, 1996.

DAVID C. PLANCHARD (2011)
Instructor, Mechanical Engineering
B.S., Northeastern University, 1980;
M.S., Worcester Polytechnic Institute, 1992.

MARKO B. POPOVIC (2010)
Assistant Research Professor, Physics
B.S., Belgrade University, 1995;
M.S., Ohio State University, 1996;
Ph.D., Boston University, 2001.

BARRY POSTERRO (2015)
Associate Teaching Professor, Mathematical Sciences
B.S., Worcester Polytechnic Institute, 1999; M.S., 2000;
M.S., 2010.

ADAM C. POWELL, IV (2018)
Associate Professor, Mechanical Engineering
S.B., Massachusetts Institute of Technology, 1992, Ph.D., 1997.

REETA PRUSTY RAO (2005)
Professor, Biology and Biotechnology
B.S., Birla Institute of Technology and Science (India), 1991;
M.S., Drexel University, 1994;
Ph.D., Penn State University Medical College, 1999.

MILOSH PUCHOVSKY (2002)
Professor of Practice, Fire Protection Engineering
B.S., Worcester Polytechnic Institute, 1988; M.S., 1991.

CRAIG B. PUTNAM (2010)
Instructor and Associate Program Director, Robotics Engineering Program
B.S., St. Lawrence University, 1974;
M.S., Penn State University, State College, 1976;
ABD, MSTE, Tufts University (current)

RICHARD S. QUIMBY (1982)
Associate Professor, Physics
B.S., Clarkson College of Technology, 1975;
Ph.D., University of Wisconsin at Madison, 1979.

PRADEEP RADHAKRISHNAN (2014)
Assistant Teaching Professor, Mechanical Engineering
B.E., PSG College of Technology, India, 2006;
M.S.E., The University of Texas at Austin, 2010; Ph.D., 2014.

MICHAEL J. RADZICKI (1990)
Associate Professor, Social Science and Policy Studies
B.A., St. Norbert College, 1979;
M.A., University of Notre Dame, 1982; Ph.D., 1985.

NIMA RAHBAR (2012)
Associate Professor, Civil and Environmental Engineering
B.S., Sharif Institute of Technology, 1998;
M.S., Northeastern University, 2003;
Ph.D., Princeton University, 2008.

SUNDARI RAMABHOTLA (2019)
Assistant Teaching Professor, Electrical and Computer Engineering
B.S., JNTU (India), 2007;
M.S., California State University, Long Beach, 2010;
Ph.D., Texas Tech University, 2015.

L. RAMDAS RAM-MOHAN (1978)
Professor, Physics; Professor, Electrical and Computer Engineering
B.S., Delhi University (India), 1964;
M.S., Purdue University, 1967; Ph.D., 1971.

ALI S. RANGWALA (2006)
Professor, Fire Protection Engineering
B.S., Government College of Engineering (India), 2000;
M.S., University of Maryland, 2002;
Ph.D., University of California, San Diego, 2006.

PRATAP M. RAO (2013)
Associate Professor, Mechanical Engineering
B.S., Worcester Polytechnic Institute, 2007;
Ph.D., Stanford University, 2013.

DANIEL REICHMAN (2019)
Assistant Professor, Computer Science
B.A., The Open University, Israel, 2002;
B.A., The Hebrew University, Israel, 2002;
Ph.D., Tel Aviv University, 2010;
M.Sc., Ph.D., Weizmann Institute of Science, Israel, 2004, 2014.

AMANDA ZOE REIDINGER (2014)
Instructor, Biomedical Engineering
B.S., Virginia Commonwealth University, 2008;
Ph.D., Worcester Polytechnic Institute, 2015.

FARNOUSH RESHADI (2020)
Assistant Professor, Foise Business School
B.Sc., Bu-Ali Sina University, Iran, 2009;
M.Sc., Iran University of Technology, 2012;
Ph.D., University of Tehran, Iran, 2020.

GONZALO CONTADOR REVETRIA (2019)
Post-Doctoral Scholar, Mathematical Sciences
M. Eng., Universidad De Chile, 2011;
M.S., University of Wisconsin, 2018;
Ph.D., University of Virginia, expected 2019.

MARK W. RICHMAN (1985)
Associate Professor, Mechanical Engineering
B.S., State University of New York at Buffalo;
M.S., University of Michigan, 1979;
Ph.D., Cornell University, 1983.

KENT J. RISSMILLER (1988)
Dean, Interdisciplinary and Global Studies Division, ad interim; Associate Professor, Social Science and Policy Studies
A.B., Muhlenberg College, 1976;
J.D., Franklin Pierce Law Center, 1980;
M.A., Syracuse University, 1981; Ph.D., 1986.

ANGEL A. RIVERA (1994)
Associate Professor, Humanities and Arts
B.A., University of Puerto Rico, 1983; M.A., 1987;
Ph.D., Rutgers University, 1994.

CHARLES D. ROBERTS (2018)
Assistant Professor, Computer Science/Interactive Media and Game Development
B.M., James Madison University, 1997;
M.A., Columbia University, 2005;
MA, University of California at Santa Barbara, 2009, Ph.D., 2014.

LOUIS ROBERTS (2015)
Associate Teaching Professor, Biology and Biotechnology
B.S. Worcester Polytechnic Institute, 1992;
Ph.D., Cornell University, 1998.

SUSAN C. ROBERTS (2015)
Professor and Department Head, Chemical Engineering
B.S., Worcester Polytechnic Institute, 1992;
Ph.D., Cornell University, 1998.

ANGELA C. INCOLLINGO RODRIGUEZ (2018)
Assistant Professor, Social Science and Policy Studies
B.A., Rutgers University, 2012;
M.A., University of California, Los Angeles, 2015; Ph.D., 2018.

JOSHUA ROHDE (2017)
Assistant Teaching Professor, Humanities and Arts
Bachelor of Music, B.S., University of Minnesota, 2011;
M.A., University of Birmingham, 2014;
Master of Sacred Music, Doctor of Musical Arts, Boston University, 2017.

MARSHA W. ROLLE (2007)
Associate Professor, Biomedical Engineering
B.S., Brown University, 1995;
Ph.D., University of Washington, 2003.

DERREN ROSBACH (2012)
Associate Teaching Professor, Global School and Civil Engineering and Undergraduate Studies
Ph.D., Virginia Polytechnic Institute, 2010.

JOSHUA P. ROSENSTOCK (2005)
Associate Professor, Humanities and Arts
B.A., Brown University, 1996;
M.F.A., School of Art Institute of Chicago, 2004.

JENNIFER M. RUDOLPH (2007)
Professor, Humanities and Arts, and Associate Head of Department
A.B., University of Chicago, 1985;
M.A., University of Washington, 1993; Ph.D., 1999.

CAROLINA RUIZ (1998)
Associate Professor, Computer Science
B.S., University of Los Andes, Colombia, 1988; B.S., 1989;
M.S., 1990;
Ph.D., University of Maryland, College Park, 1996.

JILL RULFS (1990)
Associate Professor, Biology and Biotechnology, and Associate Head of Department
B.S., University of Massachusetts, 1973;
Ph.D., Tufts University, 1982.

ELKE A. RUNDENSTEINER (1996)
Professor, Computer Science
B.S., Johann Wolfgang Goethe University, Frankfurt, West Germany; M.S., 1984;
M.S., Florida State University, 1987;
Ph.D., University of California, Irvine, 1992.

ELIZABETH F. RYDER (1996)
Associate Professor, Biology and Biotechnology
A.B., Princeton University, 1980;
M.S., Harvard School of Public Health, 1985;
Ph.D., Harvard Medical School, 1993.

JAMES E. RYAN (2019)
Associate Teaching Professor, Foisie Business School
B.S., M.S., Ph.D., Auburn University, 1981, 2001, 2006.

SARA SABERI (2016)
Assistant Professor, Foisie Business School
B.Sc., Shiraz University, Iran, 2004;
M.Sc., Isfahan University of Technology, Iran, 2006;
Ph.D., University Putra Malaysia, 2011;
PhD., University of Massachusetts, Amherst, 2015

KHALID SAEED (1997)
Professor, Social Science and Policy Studies
B.S., University of Engineering and Technology, Parkistan, 1968;
M.E., Asian Institute of Technology, Thailand, 1975;
Ph.D., Massachusetts Institute of Technology, 1981.

AHMET CAN SABUNCU (2017)
Assistant Teaching Professor, Mechanical Engineering
B.Sc., Yildiz Technical University, Turkey, 2005;
M.Sc., Istanbul Technical University, Turkey, 2007;
Ph.D., Old Dominion University, 2011.

AARON R. SAKULICH (2012)
Associate Professor, Civil and Environmental Engineering
B.S., Drexel University, 2009; Ph.D, 2009.

GUILLERMO F. SALAZAR (1983)
Associate Professor, Civil and Environmental Engineering
B.S., University of La Salle (Mexico), 1971;
M.Eng., University of Toronto, 1977;
Ph.D., Massachusetts Institute of Technology, 1983.

M. DAVID SAMSON (1991)
Associate Professor, Humanities and Arts
B.A., University of Chicago, 1980;
Ph.D., Harvard University, 1988.

JOHN SANBONMATSU (2003)
Associate Professor, Humanities and Arts
B.A., Hampshire College, 1984;
Ph.D., University of California at Santa Cruz, 2000.

WILLIAM SANGUINET (2015)
Senior Instructor/Lecturer, Mathematical Sciences
B.S., M.S, Ph.D., Worcester Polytechnic Institute, 2010, 2013, 2017.

WILLIAM SAN MARTIN (2018)
Assistant Teaching Professor, Humanities and Arts
B.A., Pontifica Universidad Católica de Chile, 2006;
M.A., 2011;
Ph.D., University of California, Davis, 2018.

JOSEPH SARKIS (2013)
Professor, Foisie Business School
B.S., State University of New York, Buffalo, 1985; M.B.A., 1986; Ph.D., 1992.

MARCUS SARKIS (2013)
Professor, Mathematical Science
B.S., Instito Tecnológico de Aeronáutica (Brazil), 1984;
M.S., Pontifícia Universidade Católica de Rio de Janeiro (Brazil), 1989;
Ph.D., New York University, 1994.

GABOR SARKOZY (1996)
Professor, Computer Science
Diploma, Budapest Eövös Loránd University, 1990
M.S., Rutgers University, 1994; Ph.D., 1994.

ROBERT P. SARNIE (2019)
Professor of Practice In Finance, Foisie Business School
B.S., Bridgewater State College, 1988;
M.S., Suffolk University, 1996.

BRIAN J. SAVILONIS (1981)
Professor, Mechanical Engineering
B.S., Worcester Polytechnic Institute, 1972; M.S., 1973;
Ph.D., State University of New York, 1976.

SUZANNE F. SCARLATA (2015)
Professor, Chemistry and Biochemistry
B.A., Temple University, 1979;
Ph.D., University of Illinois, Urbana-Champaign, 1984.

CHRISTOPHER SCARPINO (2011)
Instructor, Mechanical Engineering
B.A., University of Pittsburgh at Johnstown, 1985; B.S., 1990;
M.S., Worcester Polytechnic Institute, 1994.

LANCE E. SCHACHTERLE (1970)
Professor, Humanities and Arts
A.B., Haverford College, 1966;
A.M., University of Pennsylvania, 1968; Ph.D., 1970.

BRIGITTE I. SERVATIUS (1987)
Professor, Mathematical Sciences
Magister der Naturwissenschaften der Universitat Graz, Austria, 1978;
Ph.D., Syracuse University, 1987.

HERMAN J. SERVATIUS (1995)
Senior Instructor/Lecturer, Mathematical Sciences
M.S., Math, and Computer & Information Science, Syracuse University, 1982, 1986;
Ph.D., Syracuse University, 1987.

HRIDAYA SHAH (2019)
Assistant Teaching Professor, Physics
B.E., Ganpat University, India, 2003;
M.S., Ph.D., University of Massachusetts, Lowell, 2015; 2017.

PURVI SHAH (2013)
Assistant Professor, Foisie Business School
Bachelor of Commerce, University of Mumbai, India, 2000;
Master of Management Studies, University of Mumbai, India, 2003;
M.B.A., Texas Tech University, Lubbock, 2009; Ph.D., 2013.

SCARLET SHELL (2014)
Assistant Professor, Biology and Biotechnology
B.A., Smith College, 2001;
Ph.D., University of California, 2008.

SATYA SHIVKUMAR (1990)
Professor, Mechanical Engineering
B.S., Regional Engineering College, 1978;
M.S., Indian Institute of Technology, 1980;
M.S., Stevens Institute of Technology, 1987; Ph.D., 1987.

INGRID SHOCKEY (2008)
Associate Teaching Professor, Interdisciplinary and Global Studies Division
B.A., Clark University, 1987;
M.A., Brandeis University, 1991; Ph.D., 1996.

CRAIG A. SHUE (2011)
Associate Professor, Computer Science
B.S., Ohio University, 2004;
M.S., Indiana University, 2006; Ph.D., 2009.

ALBERT SIMEONI (2017)
Professor, Fire Protection Engineering, and Head of Department ad interim
B.Sc., University of Corsica, 1994;
M.Eng., IUSTI, Marseille, 1996;
M.Sc., University of Provence, 1996;
Ph.D., University of Corsica, 2000.

RICHARD D. SISSON, JR. (1976)
Director of Manufacturing and Materials Engineering;
Professor, Mechanical Engineering;
George F. Fuller Professorship (2004-2007) (2007-2010) (2010-2013)
B.S., Virginia Polytechnic Institute, 1969;
M.S., Purdue University, 1971; Ph.D., 1975.

LTC JACK SKILES (2018)

JEANINE L. SKORINKO (2007)
Professor, Social Science and Policy Studies
A.A., Simon's Rock College, 1999;
B.A., Rice University, 2001;
M.A., University of Virginia, 2004; Ph.D., 2007.

ALEXANDER D. SMITH (2010)
Associate Professor, Social Science and Policy Studies
B.A., York University, 2003;
M.A., University of Toronto, 2004;
Ph.D., University of Calgary, 2010.

GILLIAN SMITH (2017)
Assistant Professor, Computer Science
B.S., University of Virginia, 2006;
M.S., University of California, 2009; Ph.D., 2012;

THERESE M. SMITH (2018)
Assistant Teaching Professor, Computer Science
S.B., Massachusetts Institute of Technology, 1975;
M.S., Iowa State University of Science and Technology, 1982;
M.S., Ph.D., University of Connecticut, 2014, 2016;

WINSTON O. SOBOYEJO (2016)
Professor and Senior Vice President and Provost, Ad Interim
B.sc., King's College, London, 1985;
Ph.D., Churchill College, Cambridge University, England, 1988.

CARL SODERHJELM (2018)
Assistant Research Professor, Mechanical Engineering
M.Sc., Lund University, Sweden, 2013;
Ph.D., Worcester Polytechnic Institute, 2017.

ERIN T. SOLOVEY (2018)
Assistant Professor, Computer Science
M.S., Tufts University, 2007;
Ph.D., Tufts University, 2012.

GBETON SOMASSE (2015)
Assistant Teaching Professor, Social Science and Policy Studies
B.A., University of Abomey-Calavi, Benin, 1996;
M.Sc., ENSEA, Abidjan, Cote d'Ivoire, 2001;
M.A., University Cheikh Anta Diop, Dakar, Senegal, 2005;
M.A., Clark University, 2011; Ph.D., 2015.

QINGSHUO SONG (2019)
Associate Professor, Mathematical Sciences
M.A., Wayne State University, 2005; Ph.D., 2006;
B.S., Nankai University, China, 1996; M.A., 1999.

DAVID I. SPANAGEL (2005)
Associate Professor, Humanities and Arts
B.A., Oberlin College, 1982;
M.S. Ed., University of Rochester, 1984;
Ph.D., Harvard University, 1996.

ANTHONY SPANGENBERGER (2019)
Assistant Research Professor, Mechanical Engineering
B.S., Ph.D., Worcester Polytechnic Institute, 2012; 2017.

JAGAN SRINIVASAN (2012)
Associate Professor, Biology and Biotechnology
Goa University, India, 1993; M.S., 1995
Ph.D., Max Planck Institute for Developmental Biology, 2003.

JOSEPH STABILE (2015)
Instructor, Mechanical Engineering
M.S., University of Arizona, 1982;
M.S., University of Colorado, 1998.

SARAH E. STANLICK (2019)
Assistant Professor, Interdisciplinary and Global Studies Division
B.A., Lafayette College, 2004;
M.A., Brandeis University, 2008;
Ph.D., Lehigh University, 2012.

PATRICIA A. STAPLETON (2013)
Assistant Professor, Social Science and Policy Studies
B.A., Ursinus College, Pennsylvania, 2002;
M.A., Rutgers University, 2004;
M. Phil., CUNY, New York, 2010; Ph.D., 2012.

ELIZABETH J. STEWART YANG (2018)
Assistant Professor, Chemical Engineering
B.S., Worcester Polytechnic Institute, 2008;
M.S., University of Michigan, Ann Arbor, 2010; Ph.D., 2015.

ELISABETH A. STODDARD (2014)
Assistant Teaching Professor, Global School and Social Science and Policy Studies
B.A., University of Vermont, 2001;
M.S., Tufts University, 2008;
Ph.D., Clark University, 2014.

SARAH STRAUSS (2019)
Professor, Global School
B.S., Dartmouth College, 1984
M.S., San Jose State University, 1987;
Ph.D., University of Pennsylvania, 1997.

IZABELA STROE (2008)
Associate Teaching Professor, Physics
B.S., University of Bucharest (Romania), 1993; M.S., 1995;
Ph.D., Clark University, 2005.

DIANE M. STRONG (1995)
Professor and Department Head ad interim, Foisie Business School
B.S., University of South Dakota, 1974;
M.S., New Jersey Institute of Technology, 1978;
M.S., Carnegie Mellon University, 1983; Ph.D., 1988.

STEPHAN STURM (2012)
Associate Professor, Mathematical Sciences
M.S., University of Vienna, 2004;
Ph.D., TU Berlin, 2010.

JOHN M. SULLIVAN, JR. (1987)
Professor, Mechanical Engineering, and Associate Head of Department
B.S., University of Massachusetts, 1973;
B.S., Mec.E., 1977; M.S., Mec.E., 1978;
Ph.D., Dartmouth College, 1986.

BERK SUNAR (2000)
Professor, Electrical and Computer Engineering
B.S., Middle East Technical University (Turkey), 1995;
Ph.D., Oregon State University, 1998.

RALPH SUTTER (2012)
Instructor/Lecturer, Interactive Media & Game Development
B.A., New England Institute of Art, 2010.

ROBERT SWARZ (1991)
Professor of Practice, Electrical and Computer Engineering
B.E., New York University, 1967; Ph.D., 1973;
M.S., Rensselaer Polytechnic Institute, 1969;
M.B.A., Boston University, 1981.

ZACHARY TAILLEFER (2019)
Assistant Teaching Professor, Mechanical Engineering & Aerospace Engineering
B.S., M.S., Ph.D., Worcester Polytechnic Institute, 2011, 2012, 2017.

DALIN TANG (1988)
Professor, Mathematical Sciences
B.A., Nanjing Institute of Technology, 1981;
Ph.D., University of Wisconsin at Madison, 1988.

MINGJIANG TAO (2007)
Associate Professor, Civil and Environmental Engineering
B.S., Fuzhou University (China), 1997;
M.S., Tongji University (China), 2000;
Ph.D., Case Western Reserve University, 2003.

STEVEN S. TAYLOR (2002)
Professor and Dean ad interim, Foisie Business School
B.S., Massachusetts Institute of Technology, 1982;
M.A., Emerson College, 1993;
Ph.D., Boston College, 2000.

ANDREW R. TEIXEIRA (2017)
Assistant Professor, Chemical Engineering
B.S., Worcester Polytechnic Institute, 2009;
Ph.D., University of Massachusetts, Amherst, 2014.

YUNUS D. TELLIEL (2018)
Assistant Professor, Humanities and Arts
B.A., Sabanci Universtiy, Istanbul Turkey, 2004;
M.Phil., The City University of New York (CUNY), 2012;
Ph.D., 2017.

BURT S. TILLEY (2009)
Associate Professor, Mathematical Sciences
B.A., University of Lowell, 1988; B.S., 1998;
Ph.D., Northwestern University, 1994.

MICHAEL TIMKO (2013)
Associate Professor, Chemical Engineering
B.S., The Ohio State University, 1998;
M.S., Massachusetts Institute of Technology, 2001; Ph.D., 2004.

LYUBOV V. TITOVA (2014)
Associate Professor, Physics
B.Sc., Precarpathian University, Ukraine, 1998;
M.Sc., University of Notre Dame, 2002;
Ph.D., University of Notre Dame, 2005.

GEOFFREY A. TOMPSETT (2013)
Assistant Research Professor, Chemical Engineering
B.S., M.S., University of Aukland, 1993;
Ph.D., University of Waikato, 1997.

WALTER T. TOWNER (2007)
Associate Teaching Professor, Foisie Business School;
Director, Center for Innovative Manufacturing Solutions
B.S. Worcester Polytechnic Institute, 1983;
M.B.A., Babson College, 1989;
M.S., Worcester Polytechnic Institute 2001, 2003; PhD., 2013.

ANDREW C. TRAPP (2011)
Associate Professor, Foisie Business School;
B.S., Rochester Institute of Technology, 2000;
M.S., Bowling Green State University, 2006;
Ph.D., University of Pittsburgh, 2011.

ROBERT W. TRAVER (2003)
Teaching Professor, Global School
A.B., Dartmouth College 1975;
M.S., Purdue University, 1980;
Grad Diploma, University of Canterbury, NZ, 1981;
Ed.D., Harvard University, 1991.

KAREN TROY (2013)
Associate Professor, Biomedical Engineering
B.S., Washington University, St. Louis, 1999; B.S., 1999;
Ph.D., University of Iowa, 2003.

SETH TULER (2002)
Associate Professor, IGSD
B.A., The University of Chicago, 1984;
M.S., Massachusetts Institute of Technology, 1987;
Ph.D., Clark University, 1996.

BENGISU TULU (2006)
Associate Professor, Foisie Business School;
B.S., Middle East Technical University (Turkey), 1997;
M.S. 2000;
M.S., Claremont Graduate University, 2003; Ph.D., 2006.

JAMES L. URBAN (2019)
Assistant Professor, Fire Protection Engineering,
A.B., Case Western Reserve University, 2012;
M.S., Ph.D., University of California, Berkeley, 2014, 2017.

STEVEN VAN DESSEL (2013)
Associate Professor, Civil and Environmental Engineering
Diploma of Architect, Sint-Lucas Instituut, Brussels, 1990;
Ph.D., University of Florida, 2000.

RICHARD F. VAZ (1983)
Co-Director of the Director, Center for Project-Based Learning;
Director, Center for Project-Based Learning and IGSD
B.S., Worcester Polytechnic Institute, 1979;
M.S., 1984; Ph.D., 1987.

KRISHNA VENKATASUBRAMANIAN (2012)
Assistant Professor, Computer Science;
B.S., Webster University, 2001;
M.S., Arizona State University, 2004; Ph.D., 2009.

BOGDAN M. VERNESCU (1991)
Vice-Provost Research;
Professor, Mathematical Sciences
B.S., University of Bucharest, 1982; M.S., 1982;
Ph.D., Institute of Mathematics - Bucharest, 1989.

LUIS VIDALI (2009)
Associate Professor, Biology and Biotechnology
B.S., National Autonomous University of Mexico, 1993;
Ph.D., University of Massachusetts, Amherst, 1999.

DARKO VOLKOV (2004)
Associate Professor, Mathematical Sciences
B.Sc., University of Paris (France), 1993;
Ph.D., Rutgers University, 2001.

SAM WALCOTT (2019)
Associate Professor, Mathematical Sciences
B.A., Cornell University, 2001;
Ph.D., Cornell University, 2006.

HAROLD WALKER (2018)
Schwaber Professor of Environmental Engineering,
Civil and Environmental Engineering
B.S., California Polytechnic State University, San Luis Obispo, 1991;
M.S., University of California, Irvine, 1994; Ph.D., 1996.

ROBERT J. WALLS (2016)
Assistant Professor, Computer Science
B.S., M.S., University of Texas at Arlington, 2007, 2009;
Ph.D., University of Massachusetts, Amherst, 2014.

FANGFANG WANG (2019)
Associate Professor, Mathematical Sciences
B.S., Huazhong Normal University, China, 2003;
Ph.D., Wuhan University, China, 2010.

GU WANG (2015)
Assistant Professor, Mathematical Sciences
B.S., Peking University, 2007; M.S., 2010;
Ph.D., Boston University, 2013.

LIBO WANG (1990)
Research Associate Professor, Mechanical Engineering
Diploma, Tsinghua University (China), 1966;
Ph.D., Drexel University, 1991.

YAN WANG (2010)
Professor, Mechanical Engineering
B.E., Tianjin University, China, 2001; M.S., 2004;
Ph.D., University of Windsor, Ontario, 2008.

PAMELA J. WEATHERS (1979)
Professor, Biology and Biotechnology
B.S., Marquette University, 1969;
Ph.D., Michigan State University, 1974.

SUZANNE L. WEEKES (1998)
Interim Associate Dean of Undergraduate Studies
Professor, Mathematical Sciences
B.S., Indiana University, 1989;
M.S., University of Michigan, 1990; Ph.D., 1995.

DOUGLAS G. WEEKS (1980)
Teaching Professor, Humanities and Arts,
and Associate Head for the Arts;
Coordinator of Music
B.S., University of New Hampshire, 1964;
M.S., Gorham State, 1968;
M.M., University of Massachusetts., 1970;
Ed.D., Boston University, 1987.

CHAOZEN WEI (2019)
Post-Doctoral Scholar, Mathematical Sciences
B.S., Sichuan University, China, 2012;
Ph.D., The State University of New York at Buffalo, 2017

QI WEN (2011)
Associate Professor, Physics
B.S., Lanzhou University (China), 1998; M.Eng., 2001;
M.S., Brown University, 2005; Ph.D., 2007.

JONATHAN WEINSTOCK (2019)
Assistant Teaching Professor, Computer Science
B.S., Penn State University;
M.A., Ph.D., Temple University;

JOANN WHITEFLEET-SMITH (1995)
Associate Teaching Professor, Biology and Biotechnology
B.A., Hope College, 1976;
M.S., Purdue University, 1979;
Ph.D., University of Wisconsin-Madison, 1984.

JACOB WHITEHILL (2016)
Assistant Professor, Computer Science
B.S., Stanford University, 2001;
M.S., University of the Western Cape, South Africa, 2007;
Ph.D., University of California, San Diego, 2012.

CATHERINE F. WHITTINGTON (2018)
Assistant Professor, Biomedical Engineering
B.Sc., Louisiana Tech University, 2006;
Ph.D., Purdue University, 2012.

JENIFER WILCOX (2018)
Professor, Chemical Engineering
B.S., Wellesley College, 1998;
M.A., Ph.D., University of Arizona, Tucson, 2004.

CRAIG E. WILLS (1990)
Associate Professor, Computer Science, and Head of Department
B.S., University of Nebraska, 1982;
M.S., Purdue University, 1984; Ph.D., 1988.

E. VANCE WILSON
Associate Teaching Professor, Foisie Business School
B.A., Reed College, 1974;
M.S., B.A., San Diego State University, 1992;
Ph.D., University of Colorado at Boulder, 1995.

KRISTIN K. WOBBE (1995)
Co-Director of the Center for Project Based Learning and Director of the Great Problems Seminars Program
Professor, Chemistry and Biochemistry;
B.A., St. Olaf College, 1983
Ph.D., Harvard University, 1991.

SARAH WODIN-SCHWARTZ (2015)
Assistant Teaching Professor, Mechanical Engineering
B.S., Smith College, 2007;
M.S., University of California, Berkeley, 2009; Ph.D., 2013.

WILSON WONG (2015)
Assistant Teaching Professor, Computer Sciences
B.S., Massachusetts Institute of Technology, 1989;
M.B.A., Cornell University, 1991;
Ph.D., Bentley University, 2013.

DUNCAN WRIGHT (2019)
Post-Doctoral Scholar, Mathematical Sciences
M.A., University of Northern Iowa, 2014;
Ph.D., University of South Carolina, 2019 (expected)

KUN-TA WU (2017)
Assistant Professor, Physics
B.S., National Taiwan University, Taipei, Taiwan, 2003;
M.S., 2005;
Ph.D., New York University, 2014.

MIN WU (2017)
Assistant Professor, Mathematical Sciences
B.S., Nanjing University, China, 2007;
M.S., University of California, Irvine, 2008; M.Phil., 2012.

ZHEYANG WU (2009)
Associate Professor, Mathematical Sciences
B.S., Chong Qing University, China, 1998;
M.S., University of New Orleans, 2004;
M.Phil., Yale University, 2007; Ph.D., 2009.

SHARON WULF (2007)
Professor of Practice, Foisie Business School
B.S., Providence College, 1976;
M.B.A., Northeastern University, 1977;
Ph.D., Columbia Pacific University, 1984.

ALEXANDER M. WYGLINSKI (2007)
Professor, Electrical and Computer Engineering
B. Eng., McGill University (Canada), 1998; Ph.D., 2004;
M.S., Queen's University (Canada), 2000.

JING XIAO (2018)
Professor and Director of the Robotics Engineering Program
B.S., Beijing Normal University, China, 1982;
M.S., University of Michigan, Ann Arbor, 1984; Ph.D., 1990.
Ph.D., University of Michigan, Ann Arbor, 1990.

JAMAL S. YAGOOBI (2012)
Professor, Mechanical Engineering, and Head of Department;
George I. Alden Professorship in Engineering
B.S., Sharif University of Technology (Tehran), 1978;
M.S., University of Illinois (Urbana-Champaign), 1981;
Ph.D., 1984.

VADIM V. YAKOVLEV (1999)
Assistant Teaching Professor, Mathematical Sciences
M.S., Saratov State University (USSR), 1979; Ph.D., 1984.

MEI YANG (2017)
Assistant Research Professor, Mechanical Engineering
B.S., Sichuan University, China, 1999; M.S., 2002;
M.S., Pennsylvania State University, 2006;
Ph.D., Worcester Polytechnic Institute, 2012.

ERIC M. YOUNG (2017)
Assistant Professor, Chemical Engineering
B.S., Chemical Eng. & Biological Eng. University of Maine at Orono, 2008;
Ph.D., University of Texas at Austin, 2013.

ALI YOUSEFI (2019)
Assistant Professor, Computer Science
B.Sc., Iran University of Science and Technology, 1998;
M.Sc., Sharif University of Technology, Iran, 2000;
Ph.D., University of Southern California, 2014.

SEYED ZEKAVAT (2018)
Professor, Physics
B.Sc., Shiraz University, Iran;
M.Sc., Sharif University of Technology, Iran;
Ph.D., Colorado State University.

XIANGRUI ZENG(2019)
Assistant Professor, Robotics Engineering Program and Mechanical Engineering
B.S., M.S., Tsinghua University, China, 2009, 2012;
Ph.D., The Ohio State University, 2016;

HAICHONG "KAI" ZHANG (2019)
Assistant Professor, Biomedical Engineering/Robotics Engineering
B.S., Kyoto University, Japan, 2011; M.S., 2013;
M.S., John Hopkins University, 2015; Ph.D., 2017.

PATRICIA ZHANG (2019)
Assistant Professor, Chemistry and Biochemistry
B.S., The University of Texas, 2012;
Ph.D., Princeton University, 2017.

ZHONGQIANG ZHANG (2014)
Assistant Professor, Mathematical Sciences
B.S., Qufu Normal University, China, 2003;
M.S., Shangai University, China, 2006; Ph.D., 2011;
Ph.D., Brown University, 2014.

ZIMING ZHANG (2019)
Assistant Professor, Electrical and Computer Engineering
B.S., Northeastern University, 2005;
M.S., Simon Fraser University, 2010;
Ph.D., Oxford Brooks University, 2013.

HUILI ZHENG (2015)
Assistant Teaching Professor, Humanities and Arts
B.A., Nanjing University, Nanjing, China, 1995; M.A., 1998;
M.A., University of Toronto, 2003;
Ph.D., University of California, 2010.

YIHAO ZHENG (2019)
Assistant Professor, Mechanical Engineering
B.S.E., Shandong University, China, 2012;
M.S.E., Ph.D., University of Michigan, Ann Arbor, 2014, 2016;

YU ZHONG (2017)
Associate Professor, Mechanical Engineering
B.S., Sichuan University, China, 1997; M.S., 2000;
Ph.D., The Pennsylvania State University, State College, 2005.

H. SUSAN ZHOU (2005)
Associate Professor, Chemical Engineering
B.S., Huazhong University (China), 1996;
M.S., Clarkson University, 1999;
Ph.D., University of California, Irvine, 2002.

JOE ZHU (1998)
Professor, Foisie Business School
Program Director, Ph.D. Program
M.S., Southeast University (China), 1992; Ph.D., 1995;
Ph.D., University of Massachusetts, Amherst, 1998.

KEITH ZIZZA (2011)
Instructor, Computer Science/IMGD
B.S., Northern Essex Community College, UMASS Lowell, 1993.

JIAN ZOU (2014)
Associate Professor, Mathematical Sciences
B.S., Shandong University, China, 2000; M.S., 2002;
M.S., University of Connecticut, 2005; Ph.D., 2009.

ALEX A. ZOZULYA (1998)
Professor, Physics
B.S., Moscow Engineering Physical Institute, 1978;
Ph.D., Lebedev Physics Institute of the Academy of Sciences of the USSR, 1984.

WALTER ZURAWSKY (2015)
Associate Teaching Professor, Chemical Engineering
B.S., Temple University, 1979;
M.S., University of Illinois Urbana-Champaign, 1983;
Ph.D., 1984.

FACULTY EMERITI

Numerals following name indicate years of service.

ALLEN BENJAMIN (1963-1980)
Professor Emeritus, Civil Engineering

RONALD R. BIEDERMAN (1968-2004)
Professor Emeritus, Mechanical Engineering

JOHN M. BOYD (1966-1994)
Professor Emeritus, Mechanical Engineering

DAVID BROWN (1980-2017)
Professor Emeritus, Computer Science

A. FATTAH CHALABI (1959-1991)
Professor Emeritus, Civil Engineering

RONALD D. CHEETHAM (1973-2006)
Professor Emeritus, Biology and Biotechnology

EDWARD N. CLARKE (1965-1994)
Professor Emeritus

KEVIN A. CLEMENTS (1970-2008)
Professor Emeritus, Electrical and Computer Engineering

THEODORE C. CRUSBERG (1969-2010)
Professor Emeritus, Biology and Biotechnology

DAVID CYGANSKI (1980- 2018)
Professor Emeritus, Electrical and Computer Engineering

ROBERT A. D'ANDREA (1974-2005)
Professor Emeritus, Civil and Environmental Engineering

PAUL DAVIS (1970-2012)
Professor Emeritus, Mathematical Sciences

FRANK D. DEFALCO (1960-1999)
Professor Emeritus, Civil and Environmental Engineering

JAMES S. DEMETRY (1971-2000)
Professor Emeritus, Electrical and Computer Engineering

RICHARD D. DESROSIERS (1972-1991)
Professor Emeritus, Civil Engineering

DAVID B. DOLLENMAYER (1990-2012)
Professor Emeritus, Humanities and Arts

ALEXANDER EMANUEL (1974-2018)
Professor Emeritus, Electrical and Computer Engineering

WILLIAM FARR (1989-2018)
Professor Emeritus, Mathematical Sciences

DAVID FINKEL (1988-2016)
Professor Emeritus, Computer Science

ROBERT W. FITZGERALD (1963-2005)
Professor Emeritus, Civil and Environmental Engineering and Fire Protection Engineering

MALCOM S. FITZPATRICK (1977-2006)
Professor Emeritus, Civil and Environmental Engineering

LEE FONTANELLA (1993-2002)
Professor and Department Head Emeritus, Humanities and Arts

ARTHUR GERSTENFELD (1976-2011)
Professor Emeritus, Management

MICHAEL J. GINZBERG (2015-2020)
Professor and Dean Emeritus, Robert A. Foisie School of Business

LEONARD GOODWIN (1974-1989)
Professor Emeritus, Social Science and Policy Studies

LEON S. GRAUBARD (1969-2002)
Professor Emeritus, Management

ROBERT J. HALL (1956-1990)
Professor Emeritus, Mechanical Engineering and Management; Former Director of Continuing Education

WILLIAM J. HARDELL (1960-1994)
Professor Emeritus, Mathematical Sciences

EDMUND M. HAYES (1964-1997)
Professor Emeritus, Humanities and Arts

CHARLES R. HEVENTHAL (1963-1990)
Professor Emeritus, Humanities

HAROLD W. HILSINGER (1962-1998)
Professor Emeritus, Physics

MICHA HOFRI (1998-2018)
Professor Emeritus, Computer Science

ALLEN HOFFMAN (1970-2017)
Professor Emeritus, Mechanical Engineering

CHICKERY KASOUF (1990-2018)
Professor Emeritus, Management

NICHOLAS K. KILDAHL (1976-2005)
Professor Emeritus, Chemistry and Biochemistry

ROBERT E. KINICKI (1978-2016)
Professor Emeritus, Computer Science

DIETER KLEIN (1979-1999)
Professor Emeritus, Management

MICHAEL W. KLEIN (1979-1995)
Professor Emeritus, Physics

KAREN LEMONE (1981-2008)
Professor Emeritus, Computer Science

KENT P. LJUNGQUIST (1977-2016)
Professor Emeritus, Humanities and Arts

YI (ED) HUA MA, (1967-2015)
Professor Emeritus, Chemical Engineering

J. J. MALONE (1971-2000)
Professor Emeritus, Mathematical Sciences

JO ANN MANFRA (1972-2006)
Professor Emeritus, Humanities and Arts

JOHN A. MAYER (1956-1990)
Professor Emeritus, Mechanical Engineering

BRUCE C. MC QUARRIE (1960-1990)
Professor Emeritus, Mathematical Sciences

LAURA J. MENIDES (1976-2005)
Professor Emeritus, Humanities and Arts

WILLIAM R. MOSER (1981-2000)
Professor Emeritus, Chemical Engineering

WESLEY T. MOTT (1987-2017)
Professor Emeritus, Humanities and Arts

DONALD F. NELSON (1981-2004)
Professor Emeritus, Physics

FRANCIS NOONAN (1978-2008)
Professor Emeritus, Management

MERL M. NORCROSS (1952-1994)
Professor Emeritus, Physical Education and Athletics

ROBERT NORTON (1981-2012)
Professor Emeritus, Mechanical Engineering

JOHN T. O'CONNOR (1970-2010)
Professor Emeritus, Social Science and Policy Studies, and Management

JOHN A. ORR (1977-2016)
Professor Emeritus, Electrical and Computer Engineering

JAMES C. O'SHAUGHNESSY (1986-2012)
Professor Emeritus, Civil and Environmental Engineering

GILBERT H. OWYANG (1961-1990)
Professor Emeritus, Electrical Engineering

E. MALCOLM PARKINSON (1974-2008)
Professor Emeritus, Humanities and Arts

EDWARD A. PARRISH (1995-2004)
Professor Emeritus and President Emeritus

JAMES W. PAVLIK (1974-2007)
Professor Emeritus, Chemistry and Biochemistry

PEDER PEDERSEN (1987-2011)
Professor Emeritus, Electrical and Computer Engineering

JOSEPH PETRUCELLI (1978-2018)
Professor Emeritus, Mathematical Sciences

ROBERT A. PEURA (1968-2008)
Professor Emeritus, Biomedical Engineering

GEORGE PHILLIES (1985-2015)
Professor Emeritus, Physics

ROBERTO PIETROFORTE (1992-2017)
Professor Emeritus, Civil and Environmental Engineering

RYSZARD PRYPUTNIEWICZ (1978-2015)
Professor Emeritus, Mechanical Engineering

JOSEPH D. SAGE (1957-1994)
Professor Emeritus, Civil Engineering

ALFRED A. SCALA (1966-2011)
Professor Emeritus, Chemistry and Biochemistry

STANLEY M. SELKOW (1980-2012)
Professor Emeritus, Computer Science

THOMAS A. SHANNON (1973-2005)
Professor Emeritus, Humanities and Arts

RUTH SMITH (1983-2017)
Professor Emeritus, Humanities and Arts

MICHAEL M. SOKAL (1970-2005)
Professor Emeritus, Humanities and Arts

KENNETH A. STAFFORD (1999-2019)
Professor Emeritus, Robotics Engineering

ROBERT W. THOMPSON (1976-2015)
Professor Emeritus, Chemical Engineering

HELEN VASSALLO (1968-2018)
Professor Emeritus, Management

DOMOKOS VERMES (1990-2016)
Professor Emeritus, Mathematical Sciences

SUSAN VICK (1981-2018)
Professor Emeritus, Humanities and Arts

HOMER F. WALKER (1997-2018)
Professor Emeritus, Mathematical Sciences

ADRIAAN WALTHER (1972-2001)
Professor Emeritus, Physics

STEPHEN J. WEININGER (1965-2005)
Professor Emeritus, Chemistry and Biochemistry, and Interdisciplinary and Global Studies

ALVIN H. WEISS (1966-1994)
Professor Emeritus, Chemical Engineering

JERALD A. WEISS (1962-1988)
Professor Emeritus, Physics

JOHN F. WILD (1962-1992)
Professor Emeritus, Physics

DOUGLAS W. WOODS (1970-2000)
Professor Emeritus, Social Science and Policy Studies

ROBERT G. ZALOSH (1990-2006)
Professor Emeritus, Fire Protection Engineering

JOHN F. ZEUGNER (1971-2005)
Professor Emeritus, Humanities and Arts

SPECIAL PROFESSORSHIPS

DIRAN APELIAN
Howmet Professorship of Mechanical Engineering

JOSÉ ARGÜELLO
Walter and Mariam B. Rutman Distinguished Professorship in Chemistry (2012-)

NIKOS GATSONIS
John Woodman Higgins Professorship of Engineering (2016-2019)

ARNE GERICKE
John C. Metzger, Jr. Professor in Chemistry (2011-)

FRANK HOY
Paul Beswick Professorship of Innovation and Entrepreneurship (2009-)

JEAN KING
Peterson Family Professorship in Life Sciences and Biology (2017-)

DIANA LADOS
Milton Prince Higgins II Distinguished Professorship in Mechanical Engineering (2014-2017)

RAJIB MALLICK
Ralph H. White Family Distinguished Professorship (2012-)

BRAJENDRA MISHRA
Kenneth G. Merriam Distinguished Professorship in Manufacturing (2015-)

KATHRYN MONCRIEF
Paris Fletcher Distinguished Professorship in the Humanities (2019-)

UMBERTO MOSCO
Harold J. Gay Professorship in Mathematics (2005-)

KAREN KASHMANIAN OATES
Peterson Family Professorship in Life Sciences and Biology (2010-)

CARISSA PEREZ OLSEN
Leonard P. Kinnicutt Professorship (2016-2019)

RICHARD D. SISSON, JR.
George F. Fuller Professorship in Mechanical Engineering (2016-2019)

WINSTON SOBOYEJO
Bernard M. and Sophia Gordon Dean of Engineering (2016-)

HAROLD W. WALKER
Schwaber Professor of Environmental Engineering (2017-)

YAN WANG
William B. Smith Professor (2017-2023)

JAMAL YAGOOBI
George I. Alden Professorship in Engineering (2012-)

BOARD OF TRUSTEES' AWARD FOR OUTSTANDING SERVICE

1989 WILLIAM R. GROGAN

BOARD OF TRUSTEES' AWARD FOR OUTSTANDING RESEARCH AND CREATIVE SCHOLARSHIP

1981 KEVIN A. CLEMENTS
1982 AUDREY M. HARRIS
1983 LEONARD GOODWIN AND DAVID P. MC KAY
1984 ALVIN H. WEISS
1985 LEONARD B. SAND
1986 ALEXANDER E. EMANUEL
1987 MICHAEL W. KLEIN
1988 THOMAS A. SHANNON AND MICHAEL M. SOKAL
1989 ALLEN H. HOFFMAN
1990 PAUL W. DAVIS AND L. RAMDAS RAM-MOHAN
1991 RSYZARD J. PRYPUTNIEWICZ
1992 GEORGE D. J. PHILLIES
1993 WESLEY T. MOTT
1994 YI H. MA
1995 DONALD F. NELSON
1996 DAVID CYGANSKI
1996 ALBERT SACCO, JR.
1996 CHRISTOPHER H. SOTAK

1997 David C. Brown
1998 Kent P. Ljungquist
1999 William R. Moser
2000 Pamela J. Weathers
2001 Barbara E. Wyslouzil
2002 W. Grant McGimpsey
2003 Steven C. Bullock
2004 Nikolaos A. Gatsonis
2005 Homer F. Walker
2006 Diran Apelian
2007 Elke A. Rundensteiner
2008 Joel J. Brattin
2009 Anthony G. Dixon
2010 Dalin Tang
2011 Kaveh Pahlavan
2012 José Argüello
2013 Roger Gottleib
2014 Diane Strong
2015 Umberto Mosco
2016 Richard D. Sisson, Jr.
2017 Neil T. Heffernan
2018 Kristin Boudreau
2019 Yan Wang

BOARD OF TRUSTEES' AWARD FOR OUTSTANDING TEACHING

1975 Romeo L. Moruzzi
1976 John M. Boyd
1977 Frank D. DeFalco
1978 Thomas H. Keil
1979 Carlton W. Staples
1980 Allen H. Hoffman
1981 James W. Pavlik
1982 Alexander E. Emanuel
1983 Hartley T. Grandin, Jr.
1984 David Cyganski
1985 John F. Zeugner
1986 Dan H. Wolaver
1987 Richard D. Sisson, Jr.
1988 Patrick P. Dunn
1989 Harold W. Hilsinger
1990 David S. Adams
1991 Robert Long II
1992 Andreas N. Alexandrou
1993 Richard F. Vaz
1994 L. Ramdas Ram-mohan
1995 James S. Demetry
1996 Van Bluemel
1996 Nicholas K.kildahl
1997 Susan Vick
1998 Leonard D. Albano
1999 John A. Mcneill
2000 Stephen J. Weininger
2001 Stephen N. Jasperson
2002 Chrysanthe Demetry
2003 Helen G. Vassallo
2004 Judith E. Miller
2005 Robert L. Norton
2006 Jeanine D. Plummer
2007 John A. Goulet
2008 Peter R. Christopher
2009 Stephen J. Bitar
2010 Satya Shivkumar
2011 William W. Farr
2012 Sergey Makarov
2013 Mark Richman
2014 Sharon Wulf
2015 Gary Pollice
2016 Kent P. Ljungquist
2017 Stephen J. Kmiotek
2018 Natalie Farny
2019 Kenneth Stafford

TRUSTEES' AWARD FOR OUTSTANDING ACADEMIC ADVISING (Formerly Tau Beta Pi Award, 1991-1999)

1991 John F. Zeugner
1992 Mary M. Hardell
1993 John Griffin
1994 Kent P. Ljungquist
1995 Robert A. D'andrea
1996 Leonard D. Albano
1997 Jill Rulfs
1998 Michael A. Gennert
1999 Richard F. Vaz
2000 David S. Adams
2001 Alexander E. Emanuel
2002 Phillip E. Robakiewicz
2003 Jonathan R. Barnett
2004 George D. Pins
2004 Ann Garvin
2005 Jeanine D. Plummer
2006 Carolann Koleci
2007 Jon P. Abraham
2008 Kristen Billiar

2009 Sergey N. Makarov
2010 Holly K. Ault
2011 David S. Adams
2012 Marsha Rolle
2013 Destin Heilman
2014 Chrysanthe Demetry
2015 Sonia Chernova
2016 Jon Abraham
2017 John M. Sullivan
2018 Soussan Djamasbi
2019 Scarlet Shell

DENISE NICOLETTI TRUSTEES' AWARD FOR SERVICE TO COMMUNITY

2003 James P. O'Rourke
2004 William A. Baller
2005 Holly K. Ault
2006 Allen H. Hoffman
2007 Elizabeth Tomaszewski
2008 Christopher Bartley
2009 Hossein Hakim
2010 Kenneth A. Stafford
2011 Robert Krueger
2012 Christine Drew
2013 Janet Begin Richardson
2014 Chrysanthe Demetry
2015 Suzanne Weekes
2016 Brian Savilonis
2017 Adrienne Hall-Phillips
2018 Arthur C. Heinricher
2019 Linda Looft

TRUSTEES' AWARD FOR OUTSTANDING STAFF MEMBER

2014 Carol Garofoli
Wayne Atchue
2015 Margaret Brodmerkle
Jennifer Cluett
2016 Michael Dorsey
Rhonda Podell
2017 Paul Reilly
Lisa Wall
2018 Allison Darling
Suzanne Sontgerath

INDEX

Academic Advising 10
Academic Honesty Policy 212
Academic Probation 214
Academic Progress 214
Academic Resources Center 226
Academic Suspension 214
Academic Warning 214
Accreditation 285
Actuarial Mathematics 101
Actuarial Mathematics Major Program Chart 100
Administration 256
Administrative Obligations and Holds 215
Admission 242
Admissions Requirements 242
Advanced Placement 243
Application Fee 242
Applying to WPI 242
- Decision to Matriculate 242
- English as a Second Language (ESL) Program 245
- Financial Aid 242
- International Students 245
- New Student Orientation 244
- Notification 242
- Revocation of Admission 242
- Transfer Students 244
- Visiting & Interviewing 242

Advising 10
Aerospace Engineering 29, 125
Aerospace Engineering Major Course Flow Chart 31
Aerospace Engineering Program Chart 30
Air Force Aerospace Studies 32, 126
Applied Physics 111
Architectural Engineering 33, 128
Architectural Engineering Program Chart 35
Athletic Programs 110
Awards and Prizes 231

Bachelor/Master's Program 222
Basic Sciences 129
Biochemistry 54
Bioinformatics and Computational Biology 36, 129
Bioinstrumentation 42
Biology and Biotechnology 37, 130
Biology and Biotechnology Lab Courses 133
Biomaterials 43
Biomaterials and Tissue Engineering 43
Biomechanics 42
Biomedical Engineering 39, 135
Biomedical Engineering Lab Courses 137
Biomedical Engineering Program Chart 41
Biomedical Engineering Specializations 42
Biomedical Instrumentation, Biosignals and Image Processing 42
Biosignals 42
Business 44
Business/Management Engineering/ Management Information Systems Overview of Degree Requirements 45
Business, Robert A. Foisie School of 44, 138
- Accounting (ACC) 138
- Business (BUS) 138
- Entrepreneurship (ETR) 139
- Finance (FIN) 140
- Management Information Systems (MIS) 140
- Marketing (MKT) 141
- Operations and Industrial Engineering (OIE) 141
- Organizational Behavior and Change (OBC) 142

Campus Map 286
Career Development and Graduate School Advising 236
Career Development Center 236
Change of Registration Information 217
Changing Project Advisor 217
Check-In 216
Chemical Engineering 52, 142
Chemistry 55
Chemistry and Biochemistry 54, 144
- Advanced Chemistry Courses 147
- Biochemistry Courses 146
- Experimental Chemistry Sequence 145
- General Chemistry Sequence 144
- Inorganic and Physical Chemistry Courses 146
- Organic Chemistry Courses 145

Civil and Environmental Engineering 57, 148
Civil Engineering Program Chart 59
Class Year 212
College Awards 231
Combined Bachelor/Master's Program 222
Commencement 212
Commitment to Pluralism 4
Computer Science 60, 150
Computer Science Concentrations 63
Computer Science Courses for Majors Flow Chart 62
Computer Science Courses for Non-Majors Flow Chart 64
Computer Science Program Chart 63
Concentration in Psychobiology 120
Concentrations 11
Concentrations for Chemical Engineering Majors 53
Concentrations for Humanities and Arts Majors 77
Cooperative Education 228
Counseling Center 226
Course Changes 216
Course Descriptions 124
Courses Qualifying for Engineering Distribution Areas 124
Cross-Registration 228
Currency of Information 284

Data Science 65, 154
Data Science Courses for Majors Flow Chart 68
Data Science Major Program Chart 67
Degree Audits 216
Degree Options 11
Degree Requirements 7
Department and Program Descriptions 29
Designation of Class Year 212
Designation of Major Area of Study 212
Directions 285
Directory Information and Release of Information 215
Double Major 212
Double Majors 12

Early Completion 212
Economic Science Program 118
Electrical and Computer Engineering 70, 155
Electrical and Computer Engineering Course Flow Chart 72
Engineering Registration and Licensing 234
Engineering Science Courses 73
Engineering Science Interdisciplinary 158
Engineering Societies 234
English as a Second Language (ESL) Program 245
Enrollment and Tuition Due Dates 245
Environmental Concentration 59
Environmental Engineering 74
Environmental Engineering Program Chart 75
Exchanges 227
Expenses 245
Enrollment and Tuition Due Dates 245
Estimated Expenses 245
- Financial Aid Upon Withdrawal/ Suspension 246
- Financial Obligations, Holds 246
- Late Fees 246
- Overload Charges 246
- Payment of Tuition Deposit 245
- Room & Board Charges Upon Withdrawal or Suspension 246
- Tuition Charges Upon Withdrawal or Suspension 246

Faculty 257
Financial Aid 247
- Alternative Financial Programs 250
- Application Procedures - Prospective Student 247
- Financial Aid Policies 249
- Forms of Aid 248
- Reserve Officer Training Corps (ROTC) Scholarships 250
- Financial Obligations, Holds, and Late Fees 246

Fire Protection Engineering 76, 160
First Year Students 222
Fundamentals of Engineering Exam 60
Fundamentals of Engineering Examination (F.E.E.) 234

Gateway Park 222
George C. Gordon Library 225
Geosciences (GE) 129
Global Projects Program 19
Goal of WPI 3
Grade Appeal and Grade Change Policy 209
Grades 208
- Cumulative Point Average 209
- Dean's List 209
- Grades for Completion of Degree Requirements 208
- Grading System 208
- Incomplete 208
- No Record 208
- Other Grades 208
- Project Grading 208
- Satisfactory Progress 208

Graduate Courses 222
Graduate Programs 237
Graduate Study 237
- Admission 238
- Combined BS/MS Programs 238
- Financial Aid 238
- Five Year Programs 239
- Part-Time Graduate Programs: Online and Campus-Based Study 239
- Registration and Tuition Payment 238
- Scholarships and Grants for Graduate Study Abroad 239

Graduation 216
Graduation with Honors 211

HECCMA Course Cross-Registration 228
Holds 215
Honesty Policy 212
Housing 251
- Furnishings and Facilities 251
- Lodging Laws 252
- Meals 252
- Occupancy 251
- Off-Campus Living 252
- Residence Halls 251
- Residence Hall Staff 251
- Room Charges 251
- Roommates 251

Humanities and Arts 76, 161
Humanities and Arts Advisors 220
Humanities and Arts Courses
- Arabic (AB) 161
- Art History/Architecture (AR) 161
- Chinese (cn) 163
- English (EN) 163
- English for International Students 166
- German (GN) 166
- History (HI) 167
- Humanities (HU) 170
- International and Global Studies 171
- Music Ensembles (MU) 174
- Music (MU) 172
- Philosophy (PY) 174
- Religion (RE) 176
- Writing (WR) and Rhetoric (RH) 178
- Humanities and Arts Minors 80
- American Studies 80
- Chinese Studies 81
- Drama/Theatre 82
- English 82
- History 83
- Language (German or Spanish) 82
- Media Arts 83
- Music 83
- Philosophy and Religion 84
- Writing and Rhetoric 84

Humanities and Arts Requirement 22
Humanities and Arts with American Studies Concentration 77
Humanities and Arts with Environmental Studies Concentration 78
Humanities and Arts with Humanities Studies of Science and Technology Concentration 79

Image Processing 43
Independent Study 179, 218
Individually Sponsored On-Campus IQP Programs 21
- Center for Sustainable Food Systems 21
- Energy Sustainabilty Project Center 21
- STEM Education Project Center 21
- Sustaining WPI Project Center 21

Individually Sponsored Residential Projects 21
Industrial Engineering 48

Industrial Engineering Overview of Degree Requirements 49
Information Technology Services 223
Interactive Media & Game Development 84, 179
Interactive Media & Game Development (Bachelor of Arts) 85
Interactive Media & Game Development Technology (Bachelor of Science 86
Interactive Qualifying Project 18
Interdisciplinary 182
Interdisciplinary and Global Studies 87
Interdisciplinary Minors 88
International and Global Studies 92
International Development, Environment, and Sustainability 90
International Development, Environment, and Sustainability (IDEaS) (Bachelor of Arts Degree) 90
International Students 245

Language Requirements 227
Late Fees 246
Leave of Absence 218
Liberal Arts and Engineering (Bachelor of Arts Degree) 95
Library 225

Major Area of Study 212
Major Areas of Study 8
Major in Environmental and Sustainability Studies 91
Major Qualifying Project 17
Management Engineering 47
Management Information Systems 47
MASH (Math and Science Help) Program 226
Materials Engineering 107
Mathematical Sciences 97, 184
Mathematical Sciences Major Program Chart 99
Mechanical Engineering 102, 189
Mechanical Engineering Department Concentrations 103
Mechanical Engineering Program Chart 105
Military Science 108, 192
Military Science Course Flow Chart 108
Minor in Aerospace Engineering 32
Minor in Architectural Engineering 34
Minor in Astrophysics 114
Minor in Biochemistry 56
Minor in Bioinformatics and Computational Biology 37
Minor in Biology 38
Minor in Business 50
Minor in Chemistry 56
Minor in Computer Science 63
Minor in Data Science 66
Minor in Electrical and Computer Engineering 73
Minor in Entrepreneurship 50
Minor in Environmental and Sustainability Studies 91
Minor in Global Public Health 88
Minor in Industrial Engineering 50
Minor in Interactive Media & Game Development 87
Minor in International and Global Studies 92
Minor in Law and Technology 121
Minor in Management Information Systems 51
Minor in Manufacturing Engineering 106
Minor in Materials 107
Minor in Mathematics 102
Minor in Mechanical Engineering 106
Minor in Nanoscience 89
Minor in Physics 113
Minor in Robotics Engineering 117
Minor in Science and Engineering for Development 92
Minor in Social Entrepreneurship 51
Minor in Statistics 101
Minor in Sustainability Engineering 89
Minors 11
Minors in Social Science 121
Mission of WPI 3
MQP Learning Outcomes 17
MQP Majors and Coordinators 219
MQP Project Centers 17
  Tufts University Cummings School of Veterinary Medicine 17
  University of Massachusetts Medical School Project Center 17
Music and Theatre Facilities 224

Neoma Business School, Reims & Rouen, France; Exchange 227
New Student Orientation 244
Non-Degree Students 219

Obligations 215
Off-Campus Insurance and Legal Agreements 218
Off-Campus Programs 19
Office of Disability Services 226
Office of the Registrar 216
Official Withdrawal or Leave of Absence 218
On-Campus IQP Programs 21
Overloads of Courses 216
Overload with Project 217

Part-Time Degree Students 219
Pay and Credit 217
Payment of Tuition Deposit 245
Physical Education 194
Physical Education, Recreation, and Athletics 109
Physics 110, 195
Physics and Applied Physics Programs Advising 111
Policies and Procedures 208
Policies & Practices 284
Pre-Professional Programs 114
  Five-Year Dual Bachelor/M.S. in Management (MSMG 114
  Pre-Health Programs 115
  Pre-Law Programs 115
  Teacher Preparation Program 115
Prizes 231
Probation 214
Professionally Accredited Programs 9
Professional Writing 79
Program in Actuarial Mathematics 101
Program in Applied Physics 111
Program in Mathematical Sciences 98
Project Completion 217
Project Conferences 217

Project Grading 208
Project Lead The Way 243
Project Planning 217
Project Registration 217
Project Registration Topic Codes 219
Projects 217
Projects and Research 14
Psychological Science Program 119

Qualifying Project Grading 14

Records and Audits 216
Registration 216
Registration Policy for Degree Requirements 217
Release of Information 215
Resources and Special Programs 222
Return from Leave of Absence 219
Robotics Engineering 116, 197

Social Science and Policy Studies 117, 198
- Development 198
- Economics 199
- Environmental And Sustainability Studies 200
- General Social Science 206
- Political Science, Government and Law 201
- Psychology 203

Society/Technology Studies 206
Sociology 205
System Dynamics 205
Social Science Requirement 27
Societies, Registration and Licensing 234
Society, Technology, and Policy Program 120
Spanish (SP) 176
Special Awards 231
Special Programs 222
Special Programs for First Year Students 222
Statement of Values for Undergraduate Education at WPI 3
Student Development and Counseling Center 226
Student Exchanges 227
Student Services 226
Student Development and Counseling Center 226
Subareas of Civil Engineering 58
Summer Session (Term E) 230
Suspension 214

Tissue Engineering 43
Transcript Fees 216
Transfer Credit 211
Transfer Students 244
Trustees 254
Tuition Charges Upon Withdrawal or Suspension 246
Two Towers Tradition: The Second Century 5

Undergraduate Learning Outcomes 4
University of Applied Sciences; Konstanz, Germany; Exchange 227
University Policies and Procedures 208

Wait Lists 216
Warning 214
Withdrawal from Courses 216
WPI Plan 5
Writing Center 226
Writing Courses and Advisors 227

NOTICE OF NONDISCRIMINATORY POLICY AS TO STUDENTS

It is the policy of Worcester Polytechnic Institute that each qualified individual, regardless of race, color, sex, religion, sexual orientation, national origin, age as defined by law, or handicap, shall have equal opportunity in education, employment or services of Worcester Polytechnic Institute. It is the policy of WPI to follow U.S. federal government eligibility guidelines in the administration of its institutional financial aid program.

STUDENT RESPONSIBILITIES FOR ETHICAL AND PROFESSIONAL CONDUCT

WPI expects all its students to demonstrate the highest sense of honor in respecting academic and professional traditions such as acknowledging the borrowing or use of other people's ideas. Willful violations (like plagiarism) of such academic traditions or of legal restrictions (like those regarding copyright) will be considered violations of the "Campus Code" as described in the Student Planner.

WPI education is strongly committed to project-based learning, to providing students with access to state-of-the-art technology, and to working with professionals, on and off campus. Therefore, when students are exposed to proprietarial and/or confidential information, they must accept responsibilities appropriate to their preparation for life-long careers in which codes of ethics govern professional conduct.

Facilities such as the off-campus projects, employment sites, and on-campus laboratories permit students to gain experience with techniques at the forefront of industrial and research development. With this access comes the added responsibility of safeguarding students of any agreements they sign regarding conditions or restrictions for access to certain equipment or information will also be considered a violation of the "Campus Code" as described in the Student Planner.

Record of any penalties assigned by the WPI Campus Judicial System which result from violation of standards of ethical conduct will become a permanent part of that student's disciplinary record.

STUDENT ABSENCE DUE TO RELIGIOUS BELIEFS

Section 2B, Chapter 151C of the General Laws of the Commonwealth of Massachusetts: "Any student in an educational or vocational training institution, other than a religious or denominational educational or vocational training institution, who is unable, because of his/her religious beliefs, to attend classes or to participate in any examination, study, or work requirement on a particular day shall be excused from any such examination or study or work requirement, and shall be provided with an opportunity to make up such examination, study, or work requirement which he/she may have missed because of such absence on any particular day; provided, however, that such makeup examination or work shall not create an unreasonable burden upon such school. No fees or any kind shall be charged by the institution for making available to the said student such opportunity. No adverse or prejudicial effects shall result to any students because of his/her availing himself/herself of the provisions of this section."

POLICY FOR INSTITUTIONAL CHARGES AND REFUNDS FOR STUDENTS CALLED TO MILITARY ACTION

WPI recognizes the obligations of our students who are called to active duty by the U.S. Military. To support these students WPI has established this policy to facilitate their transition from, and back to active student status.

Such students shall receive 100% refund for the uncompleted term(s) of the semester at the date of the notice. If such student has a loan obligation to WPI they will be granted an in-school deferment status during the period of active duty service, not to exceed a total of three years.

To initiate the process to be classified "On leave for military service" the student must indicate, in writing, that he/she is requesting school deferment status while being called to active duty. A copy of the official call to active duty notice from the military must be included with this request and be submitted to the Registrar's Office.

CURRENCY OF INFORMATION

The information contained in this Undergraduate Catalog is not a complete statement of all the policies, practices, rules and regulations of Worcester Polytechnic Institute. Any statement made in this publication is for current informational purposes only and is subject to change by the governing body of WPI or its duly authorized representatives. Certain policies, rules and regulations are not published in this publication but are promulgated directly by the appropriate department. Members of the WPI community are expected to abide by the current policies, practices, rules and regulations of the college, even though they may not be contained in this publication or may not be consistent with the information contained in this publication, whether due to a properly authorized change or to a printing error.

Changes, deletions, and additions authorized by the governing body of WPI, after the printing of this catalog, are posted on WPI's web page at www.wpi.edu/ as a supplement to the undergraduate catalog, and includes the effective date of the action.

ACCREDITATION

Worcester Polytechnic Institute is accredited by the New England Association of Schools and Colleges, Inc., through its Commission on Institutions of Higher Education.

Accreditation of an institution of higher education by the New England Association indicates that it meets or exceeds criteria for the assessment of institutional quality periodically applied through a peer review process. An accredited college or university is one which has available the necessary resources to achieve its stated purposes through appropriate educational programs, is substantially doing so, and gives reasonable evidence that it will continue to do so in the foreseeable future. Institutional integrity is also addressed through accreditation.

Accreditation by the New England Association is not partial but applies to the institution as a whole. As such, it is not a guarantee of every course or program offered, or the competence of individual graduates. Rather, it provides reasonable assurance about the quality of opportunities available to students who attend the institution.

Inquiries regarding the accreditation status by the New England Association should be directed to the Office of the Provost.

The aerospace engineering, architectural engineering, biomedical engineering, chemical engineering, civil engineering, electrical and computer engineering, environmental engineering, industrial engineering, and mechanical engineering programs are accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org

The Chemistry and Biochemistry Department and its program at WPI are approved by the American Chemical Society for a major in chemistry or biochemistry. Those chemistry majors who complete a program satisfying the guidelines established by the American Chemical Society are certified to that organization as having received an undergraduate professional education in chemistry or biochemistry.

The undergraduate and graduate business offerings in the Robert A. Foisie School of Business are accredited by AACSB International, the Association to Advance Collegiate Schools of Business. AACSB International is a not-for-profit organization consisting of more than 900 educational organizations and corporations. Its mission is excellence in management education in colleges and universities. Headquartered in Tampa, Florida, AACSB International is the premier accrediting agency and service organization for business schools.

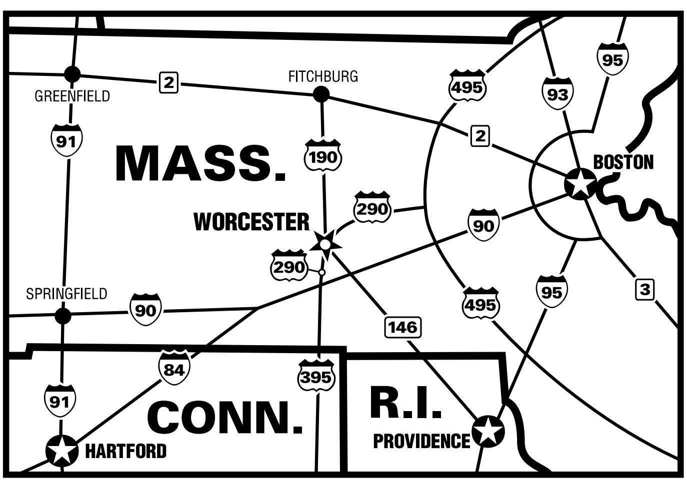
DIRECTIONS

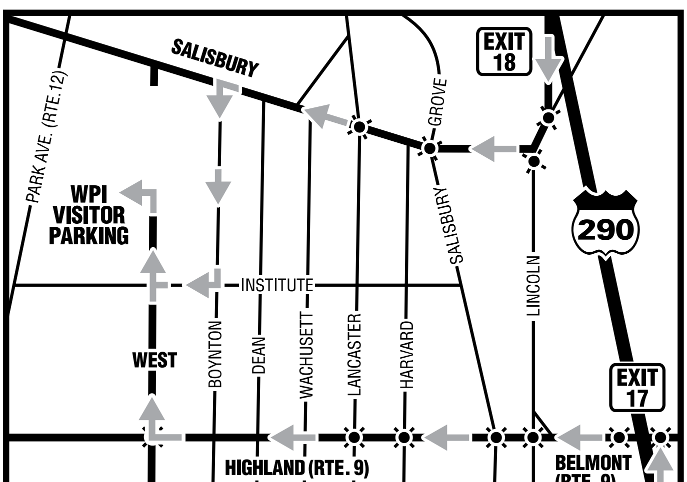
DRIVING TO WPI

FROM THE EAST:
Take Mass. Turnpike (I-90) to Exit 11A (I-495). Proceed north to I-290, then west into Worcester. Take Exit 18, turn right at end of ramp, then an immediate right before next traffic light. At next light, proceed straight through, bearing to the right on Salisbury St. At the WPI sign, turn left onto Boynton St., then right onto Institute Rd., then right onto West St. Visitor parking is on the left after footbridge.

FROM THE NORTH:
Take I-495 south to I-290. Follow directions as from east.

FROM THE SOUTH AND WEST:
Take Mass. Turnpike (I-90) to Exit 10 (Auburn). Proceed east on I-290 into Worcester. Take Exit 17, turn left at end of ramp, follow Rte. 9 west through Lincoln Sq., straight onto Highland St., then right at light onto West St. and through first intersection. Visitor parking is on the left after footbridge.





Campus Map

UNIVERSITY BUILDINGS

1 37 Lee Street
2 One Drury Lane
3 15 Regent Street
4 27 Hackfeld Road
5 32 Hackfeld Road
6 Sports & Recreation Center
7 16 Einhorn Road
8 Harrington Auditorium
9 28 Trowbridge Road
10 20 Trowbridge Road
11 Higgins House
12 Rubin Campus Center
13 Foisie Innovation Studio
14 Bartlett Center
15 15-19 Schussler Road
16 Goddard Hall
17 Olin Hall
18 Higgins Laboratories
19 Alden Memorial
20 20 Schussler Road
21 Project Center
22 Stratton Hall
23 157 West Street
24 Atwater Kent Laboratories
25 Salisbury Laboratories
26 Washburn Shops and Stoddard Laboratories
27 Power House
28 Boynton Hall
29 Fuller Laboratories
30 Gordon Library
31 Kaven Hall
32 Skull Tomb
33 Campus Police
34 35/37 Institute Road
35 108 Grove Street
36 85 Prescott Street
37 60 Prescott Street
38 50 Prescott Street

RESIDENTIAL BUILDINGS

A Hackfeld House
B Stoddard Complex
C Morgan Hall
D Ellsworth Apartments
E Trowbridge House
F Daniels Hall
G Fuller Apartments
H Messenger Hall
I Sanford Riley Hall
J Schussler House
K Salisbury Estates
L Elbridge House
M East Hall
N Founders Hall
O Institute Hall
P Faraday Hall

GREEK HOUSES

G1 Alpha Xi Delta
G2 Alpha Tau Omega
G3 Alpha Pi
G4 Alpha Gamma Delta
G5 Phi Sigma Sigma
G6 Sigma Phi Epsilon
G7 Phi Gamma Delta
G8 Alpha Chi Rho
G9 Sigma Pi
G10 Phi Sigma Kappa
G11 Theta Chi
G12 Zeta Psi
G13 Lambda Chi Alpha
G14 Phi Kappa Theta
G15 Tau Kappa Epsilon
G16 Sigma Alpha Epsilon
G17 Chi Omega

WPI

100 Institute Road
Worcester, MA, 01609

GPS Address (Parking Garage):
151 Salisbury Street

KEY
- University Buildings
- Student Residences
- Greek Houses
- Parking

See reverse side for campus directory.

Visit **maps.wpi.edu** for interactive map.

Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609-2280
wpi.edu

WPI

Graduate Catalog

2020-2021

Table of Contents

Graduate Programs 2
Graduate Programs by Degree 3
Graduate and Advanced Graduate Certificates 5
Corporate and Professional Education 7
WPI Online 8
Admission Information 9
Application Requirements 11
Financial Assistance 12
Grading System and Academic Standards 13
Enrollment and Registration 16
Tuition and Fees 19
Degree Requirements 20
Theses and Dissertations 22
Student Services 23
- Aerospace Engineering 27
- Bioinformatics and Computational Biology 34
- Biology and Biotechnology 37
- Biomedical Engineering 42
- Robert A. Foisie School of Business 50
- Chemical Engineering 64
- Chemistry and Biochemistry 69
- Civil and Environmental Engineering 73
- Computer Science 80
- Computer Security 88
- Data Science 89
- Electrical and Computer Engineering 99
- Fire Protection Engineering 112
- Interactive Media & Game Development 115
- Interdisciplinary Programs 120
- Learning Sciences and Technologies 125
- Manufacturing Engineering 129
- Materials Science and Engineering 134
- Mathematical Sciences 140
- Mechanical Engineering 152
- Neuroscience 167
- Physics 171
- Robotics Engineering 178
- Science and Technology for Innovation in Global Development 187
- STEM for Educators 191
- System Dynamics 194
- System Dynamics and Innovation Management 199
- Systems Engineering 201

Index 207
Driving Directions 208

Graduate Programs

Aerospace Engineering
Master of Science in Aerospace Engineering
Ph.D. in Aerospace Engineering

Bioinformatics and Computational Biology
Master of Science in Bioinformatics and Computational Biology
Ph.D. in Bioinformatics and Computational Biology

Biology and Biotechnology*
Graduate Certificate
Master of Science in Biology/Biotechnology
Master of Science in Biotechnology
Ph.D. in Biology and Biotechnology

Biomedical Engineering*
Master of Engineering in Biomedical Engineering
Master of Science in Biomedical Engineering
Ph.D. in Biomedical Engineering

Business
Graduate Certificate
Master of Business Administration (M.B.A.)
Master of Science in Business Analytics
Master of Science in Information Technology
Master of Science in Innovation with User Experience
Master of Science in Management
Master of Science in Marketing and Innovation
Master of Science in Operations Analytics and Management
Master of Science in Supply Chain Management
Ph.D. in Business Administration

Chemical Engineering
Master of Science in Chemical Engineering
Professional Master of Science in Chemical Engineering
Ph.D. in Chemical Engineering

Chemistry and Biochemistry
Master of Science in Biochemistry
Master of Science in Chemistry
Ph.D. in Biochemistry
Ph.D. in Chemistry

Civil and Environmental Engineering
Graduate Certificate
Master of Engineering in Civil Engineering
Master of Science in Civil Engineering
Master of Science in Environmental Engineering
Interdisciplinary Master of Science in Construction Project Management
Advanced Certificate
Ph.D. in Civil Engineering

Computer Science
Graduate Certificate
Master of Science in Computer Science
Master of Science in Computer Science specializing in Computer Security
Advanced Certificate
Ph.D. in Computer Science

Data Science
Graduate Certificate
Master of Science in Data Science
Ph.D. in Data Science

Electrical and Computer Engineering
Graduate Certificate
Master of Engineering in Electrical and Computer Engineering
Master of Engineering in Power Systems Engineering
Master of Science in Electrical and Computer Engineering
Advanced Certificate
Ph.D. in Electrical and Computer Engineering

Fire Protection Engineering
Graduate Certificate
Master of Science in Fire Protection Engineering
Advanced Certificate
Ph.D. in Fire Protection Engineering

Interactive Media & Game Development
MFA in Interactive Media and Game Design
Master of Science in Interactive Media & Game Development
Ph.D. in Computational Media

Interdisciplinary Programs
Graduate Certificate in Nuclear Science and Engineering
Graduate Certificate in System Dynamics and Innovation Management
Master of Science in:
- Power Systems Management
- System Dynamics and Innovation Management
- Systems Engineering Leadership
- Systems Modeling

Ph.D. in Interdisciplinary Studies

Learning Sciences and Technologies
Master of Science in Learning Sciences and Technologies
Ph.D. in Learning Sciences and Technologies

Manufacturing Engineering
Graduate Certificate
Master of Science in Manufacturing Engineering
Ph.D. in Manufacturing Engineering

Materials Process Engineering
Master of Science in Materials Process Engineering

Materials Science and Engineering
Master of Science in Materials Science and Engineering
Ph.D. in Materials Science and Engineering

Mathematical Sciences
Master of Mathematics for Educators
Professional Master of Science in Financial Mathematics
Professional Master of Science in Industrial Mathematics
Master of Science in Applied Mathematics
Master of Science in Applied Statistics
Ph.D. in Mathematical Sciences
Ph.D. in Statistics

Mechanical Engineering
Graduate Certificate in Mechanical Engineering for Technical Leaders
Master of Science in Mechanical Engineering
Ph.D. in Mechanical Engineering

Neuroscience
Master of Science in Neuroscience

Physics
Master of Science in Applied Physics
Master of Science in Physics
Ph.D. in Applied Physics
Ph.D. in Physics

Robotics Engineering
Graduate Certificate
Master of Science in Robotics Engineering
Ph.D. in Robotics Engineering

STEM for Educators
Master of Science in Mathematics for Educators (MMED)
Master of Science in Physics for Educators (MPED)

System Dynamics
Graduate Certificate in System Dynamics
Master of Science in System Dynamics
Ph.D. in System Dynamics

Systems Engineering
Graduate Certificate
Advanced Certificate
Master of Science in Systems Engineering
Ph.D. in Systems Engineering

*Fall Semester admission only

Return to Table of Contents

Graduate Programs by Degree

WPI offers graduate study leading to the master of science, master of engineering, master of mathematics for educators, master of business administration, and the doctor of philosophy degrees.

The schedule of courses over a period of time generally allows a student taking three or four courses per semester to complete the course requirements for most Master's degree programs in about two years. Students taking two courses per semester complete the course requirements for the master of science or engineering degrees in about three years, or the master of business administration degree in about four years.

Doctor of Philosophy (Ph.D.) Degrees*

Available in the following programs:

- Aerospace Engineering
- Applied Physics
- Biochemistry
- Bioinformatics and Computational Biology
- Biology and Biotechnology
- Biomedical Engineering
- Business Administration
- Chemical Engineering
- Chemistry
- Civil Engineering
- Computational Media
- Computer Science
- Data Science
- Electrical and Computer Engineering
- Fire Protection Engineering
- Interdisciplinary Studies
- Learning Sciences and Technologies
- Manufacturing Engineering
- Materials Science and Engineering
- Mathematical Sciences
- Mechanical Engineering
- Physics
- Robotics Engineering
- Social Science and Policy Studies
- Statistics
- Systems Engineering

**available only on a full-time basis*

Master of Science (M.S.) Degrees

Available, on a full-time and part-time basis, in the following programs:

- Aerospace Engineering
- Applied Mathematics
- Applied Physics
- Applied Statistics
- Biochemistry*
- Bioinformatics and Computational Biology
- Biology/Biotechnology
- Biomedical Engineering
- Biotechnology
- Business Analytics
- Chemical Engineering*
- Chemistry*
- Civil Engineering
- Computer Science
  - – Specializing in Computer Security
- Construction Project Management
- Data Science
- Electrical and Computer Engineering
- Environmental Engineering
- Financial Mathematics
- Fire Protection Engineering
- Industrial Mathematics
- Information Technology
- Innovation with User Experience
- Interactive Media & Game Development
- Interdisciplinary Studies
  - – Power Systems Management
  - – Systems Modeling
- Learning Sciences and Technologies
- Management
- Marketing and Innovation
- Manufacturing Engineering
- Materials Process Engineering
- Materials Science and Engineering
- Mechanical Engineering
- Neuroscience
- Operations Analytics and Management
- Physics
- Robotics Engineering
- Supply Chain Management
- System Dynamics
- System Dynamics and Innovation Management
- Systems Engineering
- Systems Engineering Leadership

**available only on a full-time basis*

Master of Engineering (M.E.) Degrees

Available in the following programs:

- Biomedical Engineering
- Civil Engineering
  - – Environmental Engineering
  - – Master Builder Program
- Electrical and Computer Engineering
- Power Systems Engineering

Master of Business Administration (M.B.A.) Degree

Building on WPI's strengths as a technological university, the WPI MBA provides STEM professionals with the business skills to drive change and lead innovation within technology-based organizations. The degree requirements are described in this catalog and in a separate brochure available from the Foisie Business School at 508-831-4665, or at business.wpi.edu.

Master of Mathematics for Educators (MME) Degree

WPI offers a Master in Mathematics for Educators, a part-time program for teachers of mathematics at the middle school, secondary, and community college levels. Students in this program may earn a content-based degree afternoons and evenings while still teaching full time. Taught by professors of mathematics at WPI, the program is designed to permit the teachers to learn from professors' research interests and includes an understanding of current developments in the field. Scholarship aid, which covers approximately 40% of the cost of tuition, is available to qualified participants. The MME degree may be used to satisfy the Massachusetts Professional License requirements, provided the person holds an Initial License.

Master of Science in Mathematics for Educators (MMED) Program

Designed especially for middle school, high school and community college educators, the Master of Science in Mathematics for Educators is a part-time, afternoon and evening program of study that puts emphasis on math content courses while also incorporating core assessment and evaluation theory coursework and a culminating project designed by the participant. Participants are additionally able to keep up-to-date on the latest research by working with professors in the field. The MMED may satisfy Massachusetts requirements to move from an Initial License to a Professional License.

Master of Science in Physics for Educators (MPED) Program

Designed especially for middle school, high school and community college educators, the Master of Science in Physics for Educators is a part-time, afternoon and evening program of study that puts emphasis on physics content courses while also incorporating core assessment and evaluation theory coursework and a culminating project designed by the participant. Participants are additionally able to keep up-to-date on the latest research by working with professors in the field. The MPED may satisfy Massachusetts requirements to move from an Initial License to a Professional License.

Combined Bachelor/Master's Program

Introduction

WPI undergraduates can begin work on a graduate degree by enrolling in a combined Bachelor's/Master's program. This accelerated course of study allows students to obtain an M.S. degree after only five years of full-time work (i.e., typically one year after completion of the B.S.). Students often obtain the B.S. and M.S. in the same field or department, but with careful planning some students complete the combined B.S./M.S. program in two different fields. Students are encouraged to review the various options available for pursuing the combined B.S./M.S. program within a specific department or program by visiting the relevant section within the Graduate Catalog. (Throughout this section, "M.S." will be used to refer to all Master's-level degrees; most students who complete the combined program obtain the M.S.).

Planning Your Program

Because B.S./M.S. students use some approved courses to satisfy the requirements of both degrees simultaneously, it is crucial for them to plan their curriculum early in their undergraduate career.

The specific course and MQP requirements for a B.S./M.S. program are determined individually, so students should consult with their own advisor as well as the graduate coordinator in the department in which they plan to pursue their M.S. degree early in their Junior year. This consultation, or series of consultations, should produce a slate of approved undergraduate courses that will be used for graduate credit. Sometimes the instructors of these courses will ask B.S./M.S. students to complete additional work, or will otherwise hold them to higher standards of achievement. Note: no undergraduate credit may be counted toward a graduate business degree.

A student's advisor and graduate coordinator will also determine what role the MQP will play in the B.S./M.S. program. Sometimes the MQP provides a foundation for a thesis. In cases where the B.S. and M.S. are not awarded in the same field, the MQP usually relates to the graduate program's discipline.

Once the specific course and MQP requirements have been established, students complete a Course Selection Form which is submitted to the relevant department(s) for approval. This written agreement constitutes the set of conditions that must be met for a student to complete the B.S./M.S. program. They are a plan for completing the requirements for both degrees and they will not supersede or otherwise obviate departmental and university-wide requirements for either degree. The completed, signed form must be submitted to the Registrar before the student may matriculate in the combined program.

How to Apply

Students almost always apply for admission to the B.S./M.S. program in their Junior year, typically after they have established their curriculum and other program requirements and completed the Course Selection Form with their faculty advisors. Applications are submitted to the Office of Graduate Admissions and are processed with all other graduate applications. Once a decision has been reached, the Office of Graduate Admissions will notify the student, usually within six weeks of receiving the application.

Program Requirements

Only registered WPI undergraduates may apply for admission to the combined B.S./M.S. programs. Students are considered undergraduates, no matter what courses they have completed, until they have met all of the requirements for the Bachelor's degree. In order to receive the B.S. and the M.S., all of the requirements for both degrees must be completed.

In most departments a student may take up to four years of uninterrupted study to complete the Master's portion of the B.S./M.S. program. There are exceptions, however, so students are advised to discuss their timetable with the appropriate advisor or graduate coordinator. Students who stop registering for classes for an extended length of time may be asked to petition the Committee for Graduate Studies and Research (CGSR) to continue their program.

Credit Equivalence and Distribution

No more than 40% of the credit hours required for the Master's degree, and which otherwise meet the requirements for each degree, may be used to satisfy the requirements for both degrees. In some departments, students may not double-count more than 30% of their graduate credits. Consult the department entries in the graduate catalog for the requirements of your program.

Double-counted courses are recorded on the transcript using the credit hours/units and grades appropriate at the graduate or undergraduate levels. For students in the combined B.S./M.S. program, approved undergraduate courses are assigned graduate credit with a conversion rate of 1/3 WPI undergraduate unit = 2 graduate credit hours, while graduate courses applied toward the undergraduate degree are awarded undergraduate units with a conversion rate of 1 graduate credit hour = 1/6 undergraduate unit.

Interdisciplinary Master's and Doctoral Programs

WPI encourages interdisciplinary research. Students interested in such options should do so with the assistance of WPI faculty, as these programs require internal sponsorship (see Interdisciplinary Programs pages 2 and 120).

Return to Table of Contents

Graduate and Advanced Graduate Certificates

Keeping pace with technological advancement today is a never-ending task. WPI's innovative graduate certificate programs help technical and business professionals keep up to date with advances in technologies and business practices without a commitment to a graduate degree program. WPI offers two certificate programs: the Graduate Certificate (GC) and the Advanced Certificate (AC).

Graduate Certificate Program

The Graduate Certificate (GC) provides opportunities for students holding undergraduate degrees to continue their study in an advanced area. A bachelor's degree is the general prerequisite; however, some departments also look for related background when making admission decisions. GC students are required to complete four to six courses totaling 12 to 18 credit hours in their area of interest. GC courses can be applied to a WPI graduate degree if the student is subsequently admitted to a degree program in the same discipline.

Please refer to page 2 for the programs that offer Graduate Certificates. Additional programs may be developed in consultation with an academic adviser. For the most current listings go to https://www.wpi.edu/academics/study

Advanced Certificate Program

The Advanced Certificate (AC) provides master's degree holders with an opportunity to continue their studies in advanced topics in the discipline in which they hold their graduate degrees or that is closely related to their graduate fields. The AC includes four to six courses totaling 12 to 18 credits, none of which were included in the student's prior master's program or in any other certificate program.

Each participating department identifies one or more guideline programs; however, each student's program of study may be customized with the academic advisor's approval to satisfy the student's unique interests.

Please refer to page 2 for the programs that offer Advanced Certificates.

Additional specializations may be developed in consultation with an academic advisor.

Application Process

Application to the GC and AC requires submission of an official application form, official transcripts of all college-level work, and a $70 application fee (waived for WPI alumni) to the Office of Graduate Admissions. Individual departments may require additional information. International students may apply to certificate programs. However, for WPI to issue the I-20 form for a student visa, international students must be registered for a minimum of nine credits on campus during their first semester and must complete their program within one year. Students apply online at http://grad.wpi.edu/+apply.

Admission and Matriculation

Admission to a certificate program is granted by the faculty of the sponsoring department through the Graduate Admissions Office. A student accepted into a master's or doctoral program may apply to a certificate program only after the graduate committee of the degree (M.S. or Ph.D.) granting program or department approves, and as long as all of the following conditions are met:

1) Admitted master's or doctoral program students may be awarded one certificate for which course credits are used to satisfy requirements for both the graduate degree (M.S. or Ph.D.) and the Graduate Certificate or advanced graduate certificate.
2) Graduate course credits used to satisfy the graduate certificate or advanced graduate certificate and graduate degree (M.S. or Ph.D.) requirements cannot also be counted toward a third credential, such as a Graduate Certificate, Advanced Graduate Certificate, graduate or undergraduate degree.
3) No more than one-third of course credit applied to a Graduate Certificate or advanced Graduate Certificate or graduate degree can be earned by transfer credit.

A Graduate or Advanced Certificate will not be awarded without admission into a certificate program.

Registration Procedures

GC and AC students register at the same time as other WPI graduate students, follow the same registration procedures, and participate in the same classes.

Tuition and Fees

Tuition and fees for GC and AC students are the same as for all other WPI graduate students.

Plan of Study

Following admission, certificate students will be assigned an academic advisor. Within the first three months of admission, certificate students are required to obtain approval for their Plan of Study from their faculty advisor. The student, the academic advisor and the department will maintain copies of the Plan of Study. Students may initiate written requests to the advisor to modify the program. The student, the academic advisor and the department must retain copies of any approved program modification(s).

Academic Policies

Academic policies regarding acceptable grade point averages for certificate students follow the same guidelines as those established for degree-seeking graduate students with the following exception: If a GC or AC student's grade point average falls below 2.5 after completing nine credits, he/she will be withdrawn from the program unless the academic department intervenes.

Program Completion

Satisfactory completion of a GC or AC requires a cumulative grade point average of 3.00 or better (A = 4.0) with individual course grades of C or better. Upon satisfactory completion of the program, students will receive a certificate of Graduate Study or a Certificate of Advanced Graduate Study in the chosen discipline. Students are responsible for submitting the signed, completed Plan of Study to the Registrar's Office to receive the certificate.

Transferring from a Certificate Program to a Graduate Degree Program

Admission to a certificate program is not equivalent to admission to a degree program. However, many certificate students eventually choose to pursue a WPI degree program. Students enrolled in a certificate program who would like to pursue a master's or doctorate must meet the application and admission requirements for the specific degree program as described in the Graduate Catalog. All GC and AC course credits will apply to a WPI graduate degree provided that the student is admitted to a graduate degree program and the courses are acceptable to that degree program.

Earning a Second Certificate

A student admitted into a certificate program who wishes to work toward a second certificate program must apply to that second certificate program for admission. The application fee will be waived for the second application. Courses counted toward one certificate may not count toward any other certificate.

Return to Table of Contents

Corporate and Professional Education

WPI Corporate and Professional Education (CPE) brings expert, integrated, and practical instruction into leading organizations across the country. WPI CPE helps businesses maximize the value of their investment in their employees through education designed to target unique business and industry needs.

Through collaboration with CPE, our partners experience a wealth of benefits:

- Employees who are educated to solve immediate and strategic problems specific to their company's highest needs
- Increased employee retention due to a demonstrated commitment to employee development
- Greater collaboration across company departments
- An effective recruiting tool for attracting new talent in a competitive market

Whatever the needs of an organization, WPI CPE has the solution: from focused, single-topic programs to those integrating multiple disciplines. We tailor and deliver first-class education to our partners, giving them a competitive edge in their unique market.

Beyond offering advanced education solutions in STEM, CPE also endeavors to connect companies with the myriad resources WPI can provide them, including research, project sponsorship, and a talent pipeline for internships and full-time employment opportunities.

Corporate Graduate Programs

For decades WPI has collaborated with businesses to develop meaningful employee education that makes sense for their workforce. We offer a completely customizable experience, including on-site and online instruction options.

Our experienced staff develops and delivers programs designed to meet a specific company's needs:

- Single courses, graduate & undergraduate certificate programs, and full graduate degree programs
- A variety of disciplines: science, engineering, technology, and management
- Interdisciplinary tracks covering multiple topics
- Instruction from both technical and managerial perspectives

Whether delivered on-site or online, WPI's corporate programs are held to the university's high standards:

- Plans of study comply with applicable state and federal education-board requirements
- Concepts and materials are consistent with on-campus courses, and customized to each company
- All faculty are appointed by WPI academic department heads
- All faculty members are experts in their fields, and many are working on cutting-edge research in their disciplines

WPI Programs Available through CPE

Corporate and Professional Education extends WPI's campus and highly technical education to interested companies by facilitating onsite delivery of a number of WPI graduate programs.

The CPE office works closely with clients to design and deliver educational solutions to their workforces. Students in these programs earn the same degrees as their on-campus counterparts.

Businesses currently benefit from the following WPI programs, and others, at their locations:

- Bioscience Management: Master of Science
- Biotechnology: Master of Science
- Computer Science: Master of Science
- Data Science: Master of Science
- Electrical & Computer Engineering: Master of Science
- Interdisciplinary Studies: Power Systems Management
- Mechanical Engineering: Master of Science
- Power Systems: Master of Science & Master of Engineering (MEng)
- Robotics Engineering: Master of Science
- Systems Engineering: Master of Science
- Systems Engineering Leadership: Master of Science
- Master of Business Administration (MBA)

Other select on-campus programs from WPI are available for onsite corporate delivery.

Contact and Information:

For more information, please contact WPI Corporate and Professional Education online, by phone, or by email:

cpe@wpi.edu

+1-508-831-5517

https://www.wpi.edu/employers-partners

WPI Online

WPI Online programs are designed with the working professional in mind. No matter your location or schedule, an advanced degree from WPI is within reach.

For more than thirty years, we have delivered superior distance education to graduate students around the world. It is our mission to make sure each student feels connected, supported, and successful.

Our online students receive the same world-class instruction as our on-campus students, delivered by expert WPI faculty. Support services tailored to the needs of working professionals are also available, in addition to the resources offered to every WPI student.

Quality Graduate Education

Our convenient online courses are open to both on-campus and distance learners.

All courses and degrees delivered online contain the same content and material one would receive in a traditional classroom, and students earn the same certificates and degrees as their on-campus counterparts. In addition, online students have the benefit of 24/7 access to their courses.

Please note: online students are held to the same high standard as all WPI students. They are expected to keep pace with course content and engage actively in all of their courses, adding value to the collaborative learning environment.

This level of participation requires regular access to high-speed Internet via a personal computer.

Programs of Study

WPI offers online graduate programs in a wide array of topics, with new programs added throughout the academic year.

Please visit online.wpi.edu for the most current online offerings.

Student Services

Online students have unique questions, concerns, and needs. With WPI Online, you're never alone. You will benefit from the services our on-campus students receive, and then some, including:

- Online orientation
- Virtual library access
- Software & mobile support
- Career counseling & placement
- Tuition & financial aid help

Plus, a dedicated team provides our online students with individualized support every step of the way, from application to graduation.

Contact and Information:

WPI Online provides online graduate students with personalized assistance and acts as their liaison to all other university offices. Students can reach WPI Online via the website, by phone, and by email:

WPI Online

online@wpi.edu

+1-508-831-5517

www.wpi.edu/+online

WPI is registered in many states including the Minnesota Office of Higher Education pursuant to Minnesota Statutes sections 136A.61 to 136A.71. Registration is not an endorsement of the institution. Credits earned at the institution may not transfer to all other institutions

Return to Table of Contents

Admission Information

Applying to WPI

Prospective graduate students submit their applications for all WPI graduate programs online at www.grad.wpi.edu/+apply.

Each department requires different credentials for admission. A table of each department's requirements can be found on page 11.

A completed undergraduate degree is a pre-requisite for beginning all graduate degree programs at WPI. All graduate students are expected to have completed their undergraduate degree at the time of matriculation.

WPI admission requirements include the following:

- A completed Application for Admission to Graduate Study.
- A non-refundable $70 application fee (waived for WPI alumni and matriculating WPI students).
- College transcripts in English and the original language from all accredited degree-granting institutions attended. Admitted students must provide official transcripts with an indication that the bachelor's degree has been awarded before they matriculate.
- Three letters of recommendation from individuals who can comment on the applicant's qualifications for pursuing graduate study in the chosen field. Applicants are required to invite their recommenders to submit letters through the online application only.
- Several programs require a statement of purpose (see page 11). This is a brief essay discussing background, interests, academic intent, and the reasons the applicant feels s/he would benefit from the program. The statement of purpose must be submitted electronically with the online application.
- The School of Business requires all applicants to submit a resume and video essay electronically with the online application.
- Proof of English language proficiency must be submitted by all applicants for whom English is not their first language. Applicants must submit an official score report from either the TOEFL (Test of English as a Foreign Language) or IELTS (International English Language Testing Service). WPI does not accept paper copies of these scores; only official scores sent electronically from the testing service will be accepted. The minimum scores for admission are:
  TOEFL: 84 (internet-based test)
  IELTS: 7.0 overall band score with no sub-score lower than 6.5

These are the minimum scores for admission to WPI. Some departments have higher minimums. Students being considered for a Teaching Assistant position will have a higher required minimum TOEFL. Please see the section on Financial Information/ Teaching Assistantships for more details.

Applicants who have completed two years of full-time study at a college or university in the U.S., the U.K., Ireland, Australia, New Zealand, or the Anglophone regions of Africa, Canada, or the Caribbean, within five years of matriculating at WPI are not required to submit TOEFL or IELTS scores.

WPI's institutional code for the TOEFL is 3969. Scores are valid for two years from the test date. For more information, or to take the TOEFL, go to: www.toefl.org. For more information on the IELTS, or to take the exam, go to: www.ielts.org.

- Some programs require the GRE (Graduate Record Examination). Consult the table on page 11 for program requirements. The business school requires the GMAT or GRE. There is no WPI minimum GRE or GMAT score for admission. WPI's institutional code for the GRE and GMAT is 3969. Scores are valid for five years from the test date. For more information, or to take the GRE go to: www.ets.org/gre or www.gmat.com.

The Office of Graduate Admissions will retain incomplete applications and their associated credentials for one year after the application was started. If the application remains incomplete for one year, WPI reserves the right to cancel it and destroy all associated documents and credentials.

All applications, letters of recommendation, and all support material become the property of WPI once they have been received by the Office of Graduate Admissions.

Three-Year Bologna-Process Degrees

WPI welcomes applications from students who have three-year Bologna-compliant undergraduate degrees from European universities. Applicants who hold these credentials will be evaluated for admission on a case-by-case basis.

Priority Dates

Students who want to apply for fall admission should submit their applications by the preceding January 1st and complete the dossier as soon as possible after that date.

Students who are seeking admission to the spring semester should submit their applications by the preceding October 1st and complete the dossier as soon as possible after that date.

Some departments have strict deadlines; others admit students year-round. Consult the WPI website for more details.

Funding is disbursed by the admissions committees in each of the academic departments. These decisions are made in tandem with the admissions decision, so there is no separate application for assistantships or fellowships.

Prospective students must indicate that they want to be considered for funding when they apply for admission. The application should be complete on or before January 1st to ensure consideration. Applications that are completed during the two weeks following January 1st will also receive the earliest consideration for funding.

With each passing month the availability of funds decreases, so applications should be completed, if possible, before the end of January.

Admission

Each department, program, or sponsoring group is responsible for making admissions decisions. Their decisions are communicated by the Office of Graduate Admissions. In general, offers of admission are good for one year.

Sometimes a department will recommend admission to a degree program that differs from the program specified in the student's application. Most typically, a department will admit a Ph.D. applicant to a Master's program. Students in such a position should contact the graduate coordinator in their program to find out what criteria they will have to meet to gain admission to the Ph.D. program in the future.

A current WPI graduate student who would like to complete a second graduate degree in another department must apply for admission to the second program. In general, standard application procedures are followed, but a copy of the first application and its supporting materials can sometimes be used as the basis for the second. No application fee is required. Students who wish to change from one degree program to another must complete a second graduate application.

Under some circumstances a student not yet admitted to a program may earn graduate credit towards the requirements for a graduate degree. But such students must keep in mind that permission to register does not constitute admission to a degree or certificate program, nor does it guarantee admission. It is also important to bear in mind that the number credits that can be applied to the degree is limited. Students are thus encouraged to apply for admission to a program at the earliest possible date.

Applicants who would like to be considered for more than one degree program must complete and submit a separate application form for each program.

Confirmation of Admission

Admission to a WPI graduate program is officially granted via a letter from the Office of Graduate Admissions. No other communication from the university (e.g., email from a department) confers admission on an applicant.

The official admission letter asks students to respond to their offer online on the Graduate Admission Response Form. Communication with the department or program directly does not officially confirm the intention to attend, and may not initiate the necessary steps for enrollment.

A non-refundable deposit of $500, which will be credited to tuition and fees, is required of students in the graduate science and engineering programs who plan to attend.

A non-refundable deposit of $1,500, which will be credited to tuition and fees, is required of students in the business school programs who plan to attend.

Deferred Enrollment

An admitted student who wishes to defer enrollment must make a request in writing to the Office of Graduate Admissions. Students typically receive a one-time deferral of up to twelve months. Funded students generally can not defer their funding. WPI requires a $500 non-refundable deposit for all graduate science and engineering student deferrals. A $1,500 non-refundable deposit is required for all business school student deferrals. This deposit will be credited to the student's tuition upon arrival.

Return to Table of Contents

Application Requirements

Graduate Certificates

Applicants to all graduate certificate programs must submit the following credentials for the application to be complete.

1. Online application form
2. Transcripts from all colleges or universities attended, and official proof of a completed Bachelor's degree before matriculating.
3. Proof of English proficiency (for non-native English speakers)
4. $70 application fee

Individual departments may require additional information.

Master's and Doctoral Degrees

Applicants to all graduate degree programs must submit the following credentials for the application to be complete.

1. Online application form
2. Transcripts from all colleges or universities attended, and official proof of a completed Bachelor's degree before matriculating.
3. Three letters of recommendation, submitted online
4. Proof of English proficiency (for non-native English speakers)
5. Exams and essays as noted below
6. $70 application fee

Department/Program	GRE	Statement of Purpose
Aerospace Engineering	Not required	Not required
Bioinformatics and Computational Biology	Required for all applicants; Waived for WPI students and alumni	Required for all applicants
Biology and Biotechnology *Fall semester admission only*	Required for all applicants	Required for all applicants
Biomedical Engineering *Fall semester admission only*	Required for all applicants; Waived for WPI students and alumni	Required for all applicants
Business	GRE or GMAT required for all applicants; see page 55 for waiver information	Required for all applicants; a resume is also required
Chemical Engineering	Required for all international applicants; Recommended for all others; Waived for WPI students and alumni	Not required
Chemistry and Biochemistry	Required for all applicants; Waived for WPI students and alumni	Required for all applicants
Civil and Environmental Engineering	Required for all international applicants; Recommended for all others; Waived for WPI students and alumni	Required for Ph.D. applicants
Computer Science	Recommended for students seeking funding	Required for all applicants
Data Science	GRE or GMAT required for international applicants; Recommended for all others; Waived for WPI students and alumni	Required for all applicants
Electrical and Computer Engineering	Required for international and Ph.D. applicants; Recommended for all others; Waived for WPI students and alumni	Required for Ph.D. applicants
Fire Protection Engineering	Required for international and Ph.D. applicants; Recommended for all others; Waived for WPI students and alumni	Required for all applicants
Interactive Media & Game Development	Recommended for all applicants	Required for all applicants; a portfolio may be submitted in addition (this is optional)
Interdisciplinary	See page 120 of the Graduate Catalog	See page 120 of the Graduate Catalog
Learning Sciences and Technologies	Strongly recommended for all applicants	Required for all applicants; a brief sample of scholarly writing is also required
Manufacturing Engineering	Required for all international applicants; Recommended for all others; Waived for WPI students and alumni	Not required
Materials Process Engineering	Required for all international applicants; Recommended for all others; Waived for WPI students and alumni	Not required
Materials Science Engineering	Required for all international applicants; Recommended for all others; Waived for WPI students and alumni	Not required
Mathematical Sciences	Recommended for all applicants; For Mathematical Sciences Ph.D., GRE Mathematics Subject Test is required	Not required
Mechanical Engineering	Recommended for all applicants	Required for all applicants
Physics	Recommended for all applicants; For Ph.D. applicants GRE Physics Subject Test is required	Required for all applicants
Robotics Engineering	Required for all applicants; Waived for WPI students and alumni	Required for all applicants
Social Science and Policy Studies	Required for all applicants	Required for all applicants
STEM for Educators	Not required	Required for all applicants
Systems Engineering	Not required	Required for all applicants

Return to Table of Contents

Financial Assistance

Financial assistance from WPI to support graduate students is available in the form of teaching assistantships, research assistantships, other graduate assistantships, fellowships, and internships, and loans. When graduate students are awarded teaching or research assistantships or fellowships that are processed through WPI, the student will receive official notification pertaining to the type and level of financial assistance from the Graduate Studies Office.

Fellowships are defined as full financial support for 12 months. They include a stipend and full tuition of at least 9 credits per semester during the academic year. In summer, there is typically no tuition offered but the fellowship recipient maintains the same stipend. Fellowships carry the specific expectations as defined in the notice of award, and are used to support the student to focus on research in their area of study.

Teaching Assistants are almost always for a full academic year of 9 months (fall and spring, or for students who begin in January, they would be for spring and at least the following fall), and include both a stipend that meets the minimum level, and full tuition of at least 9 credits per semester. The expected responsibilities of Teaching Assistants are to support courses as defined by the supporting department or program. Exceptions are made under special circumstances and must be approved by the Dean of Graduate Studies. Some approved exceptions would include: 1) the student is graduating midway through the year, 2) the support is split between RA and TA for different semesters.

Research Assistants are typically for 9 or 12 months, and must include a stipend that meets the minimum levels required for that type of student, and full tuition of at least 9 credits per semester. The expected responsibilities of Research Assistants are to support research activities as defined by the supporting faculty member.

It is possible to combine multiple sources of support. For example, a student may be a Teaching Assistant for the 9 month academic year and a Research Assistant for the 3 summer months.

For TAs and RAs that have already completed the number of credits required for their pending graduate degree, they may be offered less than 9 credits of tuition, as long as the amount is commensurate with their maintaining full-time student status.

Graduate Assistants are students that are not otherwise supported as full-time Research or Teaching Assistants or Fellows. There is no implied long-term commitment. These students typically receive hourly or fixed stipends and/or partial tuition support for a specific activity defined by a sponsor. The expected responsibilities of Graduate Assistants are typically to support research activities as defined by the sponsor. This classification is intended to provide a means for providing support to graduate students who would otherwise not receive assistantships, typically self-funded Master's students.

Student Loans

Information on financial assistance in the form of loans is available through the WPI Office of Student Aid & Financial Literacy. Students who are U.S. citizens, U.S. nationals, U.S. permanent residents, or fit into other eligible noncitizen categories set forth by the U.S. Department of Education may be eligible for federal Direct Loans, namely the Unsubsidized Loan and/or the Graduate PLUS Loan. To qualify, students must be admitted unconditionally into a graduate degree-granting program, must be enrolled on an at least a half-time basis, defined as at least four credits in a given semester, file a FAFSA, meet all other federal student aid requirements, and must be making satisfactory academic progress. Satisfactory academic progress for Direct Loan borrowing is evaluated on an annual basis at the end of the spring semester. Conditionally admitted students are not eligible for federal Direct Loans.

Private student loans are also available to students enrolled in graduate programs, certificate programs or to students who are not enrolled on an at least half-time basis. A non-citizen or international student may qualify for private loans with a creditworthy U.S. citizen or U.S. permanent resident as a cosigner.

For more information on loan programs, contact the WPI Office of Student Aid & Financial Literacy at +1-508-831-5469, and review https://www.wpi.edu/admissions/tuition-aid/applying-for-aid/graduate-students

Return to Table of Contents

Grading System and Academic Standards

Grading System

In order to assess progress throughout the graduate program, grades are assigned to the student's performance in course, project and thesis work, except in doctoral dissertation, which will be judged as ACCEPTED or REJECTED. Academic achievement in all other work is based on the following grading system:

A Excellent

B Good

C Pass

D Unacceptable for graduate credit

F Fail

AU Audit

NC No credit (not included in GPA)

P Pass; (not included in GPA)

I Incomplete; transition grade only; becomes grade of F if not changed by instructor within 12 months

W Withdrawal

SP Satisfactory progress; continuing registration in thesis/dissertation/ directed research

CR Credit for work at another institution

UP Unsatisfactory progress; this grade remains on the file transcript

AT Attended

Academic Standards

To be considered in good academic standing, graduate students must maintain a cumulative overall GPA of 3.0. Cumulative overall GPA includes all work taken since matriculation, and any coursework taken before matriculation as a graduate student, provided it has not already been counted towards another degree (exception: courses used for another WPI degree that are specifically authorized by the appropriate graduate committee to be double-counted will be included in the new degree's GPA once processed by the Registrar). Transfer credit approved from other schools is not counted in the GPA. Students are reviewed at the conclusion of each semester they are enrolled. Students who fall below the minimum standard of 3.0 cumulative overall GPA will be placed in Academic Warning.

If a student earns a grade lower than C in three or more courses, or if the cumulative overall GPA falls at or below 2.5 after attempting a minimum of 8 credits, the student is academically dismissed.

Academic Warning: Students have one semester of course work to raise their cumulative overall GPA. Students who do not improve their GPA upon the next review will move down to the next level of standing. Students who do not have a cumulative overall GPA of at least 3.0 will remain in Academic Warning.

Academic Probation: Students have one semester of course work to raise their cumulative overall GPA. Students who improve their GPA but still remain below 3.0 will be moved up to Academic Warning. Students who do not improve their GPA upon the next review will move down to the next level of standing.

Academic Dismissal: Students are academically withdrawn from the University. Students may appeal dismissal by submitting a petition to the University Registrar.

Academic standing appeal procedure: Student petitions will be reviewed by the Committee on Graduate Studies and Research. A representative from the student's home department will be present during the appeal process. This petition must be submitted with any supporting documentation no later than the date specified in the dismissal letter, typically two weeks after semester end.

Failure to complete degree milestones as specified by department/program: If a student is in otherwise good standing but fails to meet specified degree milestones, they may be dismissed from the program by the department graduate committee (see individual programs for specifics). Should this happen, the Dean of Graduate Studies and the Registrar will be notified, and the student will be academically dismissed from WPI. The student may formally apply to another degree program, but they may not attend WPI unless they matriculate to another degree program. At the department's discretion, the student may be allowed to take a lesser credential (e.g. a PhD student may be allowed to take a master's degree, or a master's student may be allowed to take a graduate certificate) if not already conferred. In this case, if necessary, the student will be allowed to complete that credential before leaving WPI.

A student is expected to expend at least 56 hours of total effort (including classroom time) for each graduate credit. This means that a student in a 3-graduate credit 14-week course is expected to expend at least 12 hours of total effort per week. A student in a 2-graduate credit 7-week course is expected to expend at least 16 hours of total effort per week.

Grade Point Average (GPA)

Grades are assigned the following grade points:
A = 4.0, B = 3.0, C = 2.0, D = 1.0 and F = 0.0. The grade point average is calculated as the sum of the products of the grade points and credit hours for each registered activity (including courses, independent studies, directed research, thesis research and dissertation research) in the average, divided by the total number of credit hours for all registered activities in the average. If a student takes the same course more than once, the course enters the GPA only once, the most recent grade received for the course being used in the average.

A student's overall GPA is calculated on the basis of all registered activities taken while enrolled as a graduate student at WPI. WPI graduate courses taken before a student had status as a degree-seeking graduate student are included in the over-all GPA. A student's program GPA is calculated on the basis of those WPI courses listed by the student on the student's Application for Graduation form. The transcript will report the overall GPA.

Courses transferred from elsewhere for graduate credit (for which a grade of CR is recorded on the WPI transcript), and courses taken to satisfy undergraduate degree requirements or to remove deficiencies in undergraduate preparation, are not included in either GPA. Registered activities in which the student receives grades of AU, NC, P, I, W, SP or UP are not included in either GPA.

Only registered activities in which a grade of A, B, C, CR, or P was obtained may be used to satisfy courses or credit requirements for a graduate degree.

Grade Appeal and Grade Change Policy

The Student Grade Appeal Procedure affirms the general principle that grades should be considered final. The principle that grades for courses, thesis credit and dissertation credit should be considered final does not excuse an instructor from the responsibility to explain his or her grading standards to students, and to assign grades in a fair and appropriate manner. The appeal procedure also provides an instructor with the opportunity to change a grade for a course or project on his or her own initiative. The appeal procedure recognizes that errors can be made, and that an instructor who decides it would be unfair to allow a final grade to stand due to error, prejudice or arbitrariness may request a change of grade for a course or project without the formation of an ad hoc committee. An instructor may request a grade change by submitting a course, thesis credit or dissertation credit grade change request in writing to the Registrar at any time prior to a student's graduation.

The purpose of the Grade Appeal Policy is to provide the student with a safeguard against receiving an unfair final grade, while respecting the academic responsibility of the instructor. Thus, this procedure recognizes that:

- Every student has a right to receive a grade assigned upon a fair and unprejudiced evaluation based on a method that is neither arbitrary nor capricious; and,
- Instructors have the right to assign a grade based on any method that is professionally acceptable, submitted in writing to all students, and applied equally.

Instructors have the responsibility to provide careful evaluation and timely assignment of appropriate grades. Course and project grading methods should be explained to students at the beginning of the semester. WPI presumes that the judgement of the instructor of record is authoritative and the final grades assigned are correct.

A grade appeal shall be confined to charges of unfair action toward an individual student and may not involve a challenge of an instructor's grading standard. A student has a right to expect thoughtful and clearly defined approaches to course and research project grading, but it must be recognized that varied standards and individual approaches to grading are valid. The grade appeal considers whether a grade was determined in a fair and appropriate manner; it does not attempt to grade or re-grade individual assignments or projects. It is incumbent on the student to substantiate the claim that his or her final grade represents unfair treatment, compared to the standard applied to other students. Only the final grade in a course or project may be appealed. In the absence of compelling reasons, such as clerical error, prejudice, or capriciousness, the grade assigned by the instructor of record is to be considered final.

Only arbitrariness, prejudice, and/or error will be considered as legitimate grounds for a grade change appeal.

Arbitrariness: The grade awarded represents such a substantial departure from accepted academic norms as to demonstrate that the instructor did not actually exercise professional judgment.

Prejudice: The grade awarded was motivated by ill will and is not indicative of the student's academic performance.

Error: The instructor made a mistake in fact.

This grade appeal procedure applies only when a student initiates a grade appeal and not when the instructor decides to change a grade on his or her own initiative. This procedure does not cover instances where students have been assigned grades based on academic dishonesty or academic misconduct. Academic dishonesty or misconduct are addressed in WPI's Academic Honesty Policy. Also excluded from this procedure are grade appeals alleging discrimination, harassment or retaliation in violation of WPI's Sexual Harassment Policy, which shall be referred to the appropriate office at WPI as required by law and by WPI policy.

The Grade Appeal Procedure strives to resolve a disagreement between student and instructor concerning the assignment of a grade in a collegial manner. The intent is to provide a mechanism for the informal discussion of differences of opinion and for the formal adjudication by faculty only when necessary. In all instances, students who believe that an appropriate grade has not been assigned must first seek to resolve the matter informally with the instructor of record. If the matter cannot be resolved informally, the student must present his or her case in a timely fashion in the procedure outlined below. Under normal circumstances, the grade appeal process must be started near the beginning of the next regular academic semester after the disputed grade is received.

Student Grade Appeal Procedure

1. A student who wishes to question a grade must first discuss the matter with the instructor of record within one week after the start of the next regular academic semester (fall or spring) or term (A, B, C or D) after receiving the grade. Late appeals will only be reviewed at the discretion of the Faculty Review Committee (FRC). In most cases, the discussion between the student and the instructor should suffice and the matter will not need to be carried further. The student should be aware that the only valid basis for grade appeal beyond this first step is to establish that an instructor assigned a grade that was arbitrary, prejudiced or in error.
2. If the student's concerns remain unresolved after the discussion with the instructor, the student may submit a written request to meet with the appropriate Department Head or Program Coordinator within one week of speaking with the instructor. The appropriate Department Head or Program Coordinator will meet with the student within one week and, if he or she believes that the complaint may have merit, with the instructor. After consultation with the appropriate Department Head or Program Coordinator, the instructor may choose to change the grade in question or leave the grade unchanged. The Department Head or Program Coordinator will communicate the result of these discussions to the student.

3. If the matter remains unresolved after the second step, the student should submit a written request within one week to the Provost's Office to request an ad hoc committee for Appeal of a Grade. The Provost's representative (the Dean of Graduate Studies, or alternate) will meet with the student and will ask the Faculty Review Committee (FRC) to appoint the ad hoc committee for Appeal of a Grade. The Chair of the FRC will select the members of the ad hoc committee and serve as its non-voting chair. The ad hoc committee for appeal of a course, thesis credit or dissertation credit grade will be composed of three faculty members. The first member will be the Department Chair, Program Coordinator or Departmental Graduate Coordinator from the instructor's Department. If all three have a conflict of interest, the Provost's representative will serve on the ad hoc committee. The remaining two members will be two FRC members with no conflicts of interest with either the student or the instructor. Apparent conflicts of interest would include the student's thesis or dissertation advisor, members of the student's graduate committee, and faculty members with close research collaboration or project advising relationships with the instructor. The Chair of the FRC requests a written statement from the student and a written response from the instructor. The ad hoc committee examines the written information and may gather additional information as it sees fit.
4. Through its inquiries and deliberations, the ad hoc committee is charged to determine whether the grade was assigned in a fair and appropriate manner or whether clear and convincing evidence of arbitrariness, prejudice, and/or error might justify changing the grade. The ad hoc committee will make its decisions by a majority vote.
5. If the ad hoc committee concludes that the grade was assigned in a fair and appropriate manner, the ad hoc committee will report its conclusion in writing to the student and the instructor. The decision of the ad hoc committee is final and not subject to appeal.
6. If the ad hoc committee determines that compelling reasons exist for changing the grade, it would request that the instructor make the change, providing the instructor with a written explanation of its reasons. At this point, the instructor may change the grade. If the instructor declines to change the grade, he or she must provide a written explanation for refusing. If the ad hoc committee concludes that the instructor's written explanation justifies the original grade, the ad hoc committee will report this in writing to the student and instructor and the matter will be closed. If the ad hoc committee concludes that it would be unjust to allow the original grade to stand, the ad hoc committee will then determine what grade is to be assigned. The new grade may be higher than, the same as, or lower than the original grade. Having made this determination, the three members of the committee will sign the grade change form and transmit it to the Registrar. The instructor and student will be advised of the new grade. Under no circumstances may persons other than the original faculty member or the ad hoc committee change a grade. The written records of these proceedings will be filed in the student's file in the Registrar's Office.

Project, Thesis, and Dissertation Advising

A graduate project, thesis, and/or dissertation must include a faculty advisor-of-record at the time of initial registration.

The only faculty members who may, by virtue of their appointment, automatically be the formal advisors-of-record for graduate projects or independent study activities (ISGs, theses, dissertations, etc.) are:

1. tenure/tenure track faculty,
2. professors of practice, or
3. others who have at least a half-time, full-year faculty appointment, with advising of independent work as part of their contractual load.

Individuals holding other faculty appointments, such as part-time adjuncts or non-instructional research professors, may co-advise and indeed are encouraged to do so where appropriate.

Department heads wishing to authorize anyone with appointments other than these three categories as an advisor of record for projects, theses, or independent studies must first obtain agreement from the Dean of Graduate Studies. (In their absence, please refer the request to the Associate Provost for Academic Affairs.)

Plan of Study

After consultation with and approval by the advisor, each admitted student must file a formal Plan of Study with the department within the first semester if full-time, and within the first year if part-time. Program changes are implemented by advisor and student. Copies of the revised Plan of Study will be maintained in department files.

Commencement Participation Policy

Master's degree graduate students who are planning to complete their final courses (maximum 6 credits) in the summer term and graduate in September are eligible to participate in the previous May Commencement ceremony. Students who have thesis requirements remaining are not eligible. Students must be registered for all remaining requirements in the summer term by April 1 of the year they will be participating in order to be approved. Students may only participate in one ceremony per degree level. Students approved to walk will not receive their diploma, nor will the degree be conferred, at the May ceremony. They will also not be listed in the Commencement program. PhD students must complete all requirements before participating in a Commencement ceremony and are not eligible to participate in an earlier ceremony. No exceptions will be made to this policy.

Enrollment and Registration

The basic requirement for enrollment in a given course is a bachelor's degree from an accredited institution in a relevant field of science or engineering. Although those with management backgrounds may enroll in graduate management courses, no prior management study is required. Persons who have been admitted to graduate study at WPI are given first priority in course registration. Persons not holding a bachelor's degree, but who might qualify through training or experience, may be allowed to enroll on either a credit or audit basis with permission of the instructor. Registration for graduate courses is on a space-available basis for nonadmitted students.

Graduate students are expected to enroll in graduate courses or thesis credit on the registration days designated in the WPI academic calendar. Registration on days not designated will result in additional fees.

Enrollment in a course or courses, and satisfactory completion of those courses, does not constitute acceptance as a candidate for any graduate degree nor does it indicate admission to any graduate program. For students seeking advanced degrees, or graduate certificates, formal admission to a graduate program is required.

International Students

International students are required to enroll no later than the final day of the add/drop period. Students must be enrolled by this time in order to be registered in the SEVIS database and to remain in legal immigration. Failure to enroll in a timely manner could jeopardize a student's legal status and ability to lawfully remain in the U.S.

Degree-Seeking Student Enrollment

Graduate students must be registered for the semester in which degree requirements are completed. For master of science programs requiring a thesis and all Ph.D. programs, students must register for a minimum of 1 semester credit hour. For master of science programs that do not require a thesis, all students must be registered for all remaining credits in the final semester of study.

Full-time degree-seeking graduate students are expected to be continuously registered during their graduate school careers, excluding the summer semester. Full-time degree seeking students who interrupt their studies and are not on an approved leave of absence will be marked 'inactive' in any fall or spring semester in which there is no registration or credit activity. Inactive status means that students do not have access to WPI buildings, services or coursework.

In recognition of the competing responsibilities faced by part-time students, WPI allows one semester without credit activity to elapse before active status is revoked. Part-time degree-seeking graduate students will be marked inactive if one semester elapses with no credit activity and the registration period of the subsequent semester ends without registration or credit activity.

Inactive students will need to complete a readmission form through the Registrar's Office. See "Readmission from Leave of Absence" section below.

Official Withdrawal

Students who wish to terminate their degree programs must complete the Graduate Withdrawal Form available on the Registrar website and submit it to the Registrar's Office. Any registrations in semesters or terms that have begun before the certified date of last attendance will receive a grade of W and the student will be exempted from academic review. Any registrations in semesters or terms that have not begun before the certified date of last attendance will be dropped. For official start dates of semesters and terms, see the Academic Calendar. For tuition adjustment information, see the "Tuition and Fees" section.

Students who have attended through the 12th week of a semester (or the 5th week of B or D terms) may not withdraw for that semester and will be academically reviewed. They may withdraw for the following semester.

Note: This applies to students officially withdrawing from the University; for an individual course withdrawal, please refer to the Course Changes section for policy and refund information.

Institutional Leave of Absence

Full-time students who wish to take a temporary leave from their degree programs and part-time students who wish to take more than one contiguous semester off must complete the Leave of Absence Form available on the Registrar website and submit it to the Registrar's Office. Students should inform themselves about consequences to financial aid, visa status, housing, and other considerations before taking an institutional leave of absence. Any registrations in semesters or terms that have begun before the certified date of last attendance will receive a grade of W and the student will be exempted from academic review. Any registrations in semesters or terms that have not begun before the certified date of last attendance will be dropped. For official start dates of semesters and terms, see the Academic Calendar. For tuition adjustment information, see the "Tuition and Fees" section.

Students who have attended through the 12th week of a semester (or the 5th week of B or D terms) may not take a leave of absence for that semester and will be academically reviewed. They may take a leave of absence for the following semester.

Note: This applies to students taking a full leave from the University; for an individual course withdrawal, please refer to the Course Changes section for policy and refund information.

Readmission from Leave of Absence

To return, a student must fill out the Graduate Readmission Form available on the Registrar website and submit it to the Registrar's Office with all required signatures at least 30 days prior to the start of the semester in which they plan to return.

Military Leave of Absence

WPI graduate students who are called to active duty by the United States military shall receive a 100% refund for the uncompleted semester at the date of the notice. If such students have a loan obligation to WPI they will be granted an in-school deferment status during the period of active duty service, not to exceed a total of three years. To initiate the process to be classified "on leave for

Return to Table of Contents

military service," a student must fill out a Leave of Absence form available on the Registrar website indicating that he/she is requesting school deferment status while being called to active duty. A copy of the official call to active duty notice from the military must be included with this request and be submitted to the Registrar's Office.

If the student has paid a tuition bill with proceeds from either a subsidized or an unsubsidized Federal Stafford Loan and has received a refund for either or both of the loans, the student shall be responsible for any overpayment of funds. It is therefore necessary for the student to contact the lender(s) upon withdrawal.

Childbirth and Adoption Accommodation Policy

In recognition of the challenges of balancing the demands of graduate study and parenting a new child, the Childbirth/Adoption Accommodation Policy aims to improve the environment for student parents. An Accommodation can be taken based on the student's individual circumstance in consultation with their Advisor and the Dean of Graduate Studies; early consultation will provide the time necessary to rearrange teaching duties for those students supported by teaching assistantships, or to adjust research/lab schedules. The purpose of this policy is to make it possible for a student to maintain registered full time student status, along with all the benefits of such status, while facilitating the return to full participation in courses, research and teaching.

Special note for TAs/RAs/Fellowship Students: During the Childbirth/Adoption Accommodation period, expectant graduate students who have been funded for the previous twelve (12) months through WPI internal TA/RA/Fellowships and who have received an award letter indicating continuing support will be eligible for salary continuation. During this timeframe, duties typically performed by TA's and RA's will be suspended for (eight weeks) and the student will not be expected to work. If the student parent is a teaching assistant, the Office of Graduate Studies will fund a temporary replacement for the affected period if necessary.

Requesting Leave: Matriculated and enrolled graduate students may formally request a Childbirth/Adoption Accommodation by emailing the Office of Graduate Studies. The student will be provided with a Childbirth/Adoption Accommodation Request form and will need to follow the appropriate procedures and documentation required. This Academic Accommodation Period is not a leave of absence from University responsibilities. The expectation is that the woman will be in residence, and assuming good health of the pregnant woman or new mother and the infant, will remain engaged in classwork and research.

Graduate Internship Experience

Graduate internship experiences are available across several programs of studies at WPI in order to enhance the professional development of Masters and Doctoral students. The graduate internship is a short-term and temporary work assignment in residence at a company or other *external* organization that forms a complementary part of a student's educational program. An internship will appear on the transcript with a minimum of 0 credits and a maximum of 3 credits (as determined by the department/program). All students require the approval of their faculty advisor-of-record to participate in an internship. Furthermore, the student and their faculty advisor-of-record will define concrete performance metrics and objectives to be achieved during the internship prior to the experience.

The graduate internship experience must align with the student's plan of study and be related to the specific graduate degree program. Because the purpose of an internship is to provide a student with a new experience, graduate students already employed full-time or part-time may not participate as interns at the same place of employment without program approval. Since the internship must be performed at an external site, WPI would not be considered an acceptable sponsor for a graduate internship. Typically, Teaching Assistants may not be on internship during the same time period during the academic year as when they are serving as a TA, but may pursue an internship over the summer or with departmental/program permission.

The graduate internship is not a University requirement, but rather an option available to all graduate students enrolled in graduate programs that permit internships. Students may pursue graduate internship experiences of up to 3 credits per degree (as determined by the department/program). Internship experiences may be completed for 0-3 credits, and multiple internship experiences across semesters may be completed. However, graduate students may be enrolled in internships during a maximum of 3 semesters, inclusive of the summer, regardless of the amount of credit assigned per internship experience. Students enrolled in full time internships, defined as more than 20 hours per week, will be deemed a full-time student for that semester. Students enrolled in part time internships, less than 20 hours, will still need to be registered for 8 or more credits, inclusive of the internship's credits, to be considered fully enrolled. For-credit internship experiences are only for matriculated students. Graduate internships may not be applied to multiple degrees (i.e., BS/MS). Resources for graduate internships and job search tools are highlighted in the Career Development Center subsection in the Graduate Catalog. Enrollment in the graduate internship experience must adhere to established add/drop deadlines. For more information about graduate internship policies and procedures, including how to register for graduate internships, please see https://www.wpi.edu/academics/graduate/internships.

For Masters Students: Students enrolled in a Master's program may participate in the graduate internship experience after successfully completing their first 12 credits of graduate coursework at WPI, provided they are in good academic standing. With approval of the program designee, Master's students participating in a graduate internship should register for the graduate internship course designated 5900.

For PhD Students: Students enrolled in a PhD program may participate in the graduate internship experience after successfully completing their first 12 credits of graduate coursework at WPI, provided they are in good academic standing. With approval of the program designee, PhD students participating in a graduate internship should register for the graduate internship course designated 6900.

Return to Table of Contents

Special Notes for International Students: An international graduate student on an F-1 visa must maintain full-time status for the duration of their graduate program. International students with F-1 visa status may apply for two types of practical training:

1. Curricular Practical Training (CPT): CPT is used for graduate level internships while students are pursuing their degrees. CPT is authorized by the university and the requirement is that the internship is an integral part of an established curriculum. Internships should be for credit.
2. Optional Practical Training (OPT): OPT is typically used by students for one year of employment after completion of degree. It can also be used in part for summer jobs or part-time employment during the academic year if employment is in the student's field of study. OPT requires approval by U.S. Customs and Immigration Services.

Non-degree Student Enrollment

Individuals with earned bachelor's degrees may wish to enroll in a single course or a limited number of courses prior to applying for admission. Non-degree students may choose to be graded conventionally (A, B, C), or on a pass/fail basis. Pass/Fail grading must be chosen at the time of registration, and courses taken on the pass/fail basis are not transferable to any master's degree program.

Non-admitted students may take a maximum of four graduate courses and receive letter grades in most departments. See department descriptions for specific information. Once these maximums are reached, additional course registrations will be changed to pass/fail and may not be used for degree credit.

Note: Non-admitted students may not take more than 6 credits of graduate business coursework prior to admission to a graduate business program.

The fact that a student has been allowed to register for graduate courses (and earn credit) does not guarantee that the student will be admitted to that department's certificate or degree program at a later date. Students are therefore encouraged to apply for admission to a degree or certificate program prior to any course registration.

Non-degree Student Course Registration

Nondegree-seeking students register for courses in the same manner as all other students. However, degree-seeking students have preference in registering for courses with limited enrollments. Non-degree graduate students are considered active only in those semesters during which they have a current registration and credit activity. They are marked as inactive in the semester following the conclusion of their credit activity, including the summer semester, provided there is no new registration.

Auditing Courses

Graduate students primarily interested in the content of a particular course may register as auditors. Students are charged a 50% reduced tuition rate per semester hour to audit a course. There is **no credit** and **no grade** awarded for classes that are audited. Students cannot audit thesis and project work.

Audit registrants are encouraged to participate in the courses, but typically do not submit written work for evaluation. Often professors will accept written work of audit registrants, but this is left to the discretion of the instructor.

A student may change from credit to audit registration, but may not change from audit to regular credit registration. To change to audit registration for any graduate course, the student must complete an audit form (available in the Registrar's Office) within the first three weeks of class. No tuition or fees will be returned to students who change to audit registration, i.e., the full tuition rate applies.

Definition of Full-Time and Part-Time Status

If a student is registered for 8 or more credits, the student is deemed to be a full-time student for that semester. If a student needs fewer than 8 academic credits to complete degree requirements, registration for the number of credits required for completion of the degree gives the student full-time status. A student pursuing a master's degree, whose Plan of Study shows completion of all degree requirements within a single two-year period, retains full-time status so long as the student complies with that Plan of Study. A student officially enrolled in a graduate internship program has full-time status during the internship period. If a student has completed the minimum number of credits required for a degree, and is certified by the department or program to be working full-time toward the degree, enrollment in 1 credit of dissertation research for a student seeking the doctorate establishes full time status. For students seeking a master's degree, 1 credit of thesis research establishes the student's full-time status with department certification. For the purposes of this rule, the semesters are fall and spring.

Transcripts

Transcripts may be requested, and there is a fee associated with each transcript. For more information, please visit www.wpi.edu/+registrar.

Course Changes

There is an add/drop period at the start of each term and the exact deadlines depend on whether the course follows a 7-week schedule or a 14-week schedule.

For 7-week courses (undergraduate and graduate), a student can add a course without a fee through the fifth day of classes. On the sixth through the tenth day of classes, students can add courses (with instructor approval) with a $100 late fee. Students can drop courses on days 1-10 of each term without incurring a late fee. For undergraduates in 7-week courses, no adds or drops are allowed after the tenth day of the term. For graduate students in 7-week courses who drop a course after the tenth day, but before the end of the fifth week of the term, a W (Withdrawal) will be assigned. Tuition will be adjusted for individual course withdrawals based on the schedule posted for Leaves of Absence and Official Withdrawal (see page 16).

For 14-week courses (undergraduate and graduate), students can make course changes (add or drop) without penalty through the tenth day of the semester. A $100 late fee will be charged for course adds after the tenth day of the semester and instructor permission is required. No drops are allowed after the tenth day of the semester; for graduate students, course withdrawals are permitted through the tenth week of the semester, and a grade of W (Withdrawal) will be assigned. Tuition will be adjusted for individual course withdrawals based on the schedule posted for Leaves of Absence and Official Withdrawal (see page 16). Consult the University calendar for specific dates.

For 10-week courses (undergraduate and graduate), students can make course changes (add or drop) without penalty through the tenth day of the semester. A $100 late fee will be charged for course adds after the tenth day of the semester and instructor permission is required. No drops are allowed after the tenth day of the semester; for graduate students, course withdrawals are permitted through the seventh week of the semester, and a grade of W (Withdrawal) will be assigned. Tuition will be adjusted for individual course withdrawals based on the schedule posted for Leaves of Absence and Official Withdrawal (see page 16)

Note: If a degree-seeking student is dropping or withdrawing from all registered course activity, they must either take an institutional leave of absence or officially withdraw from the University.

Tuition and Fees

Tuition for all courses taken by graduate students is based on a $1,610 fee per credit hour for the 2020-2021 academic year. The Graduate Student Organization Fee is $30.00 for full-time students and $15.00 for part-time students each semester. Health & Wellness fee of $195 may be charged for on campus students. See https://www.wpi.edu/offices/bursar/tuition for current tuition and fee information.

Tuition Adjustments for Leaves and Withdrawals

Tuition adjustments will follow the schedule below, based on the certified last date of attendance, for Institutional Leave of Absences and Official Withdrawals. Any registrations in semesters or terms that have not begun before the certified date of last attendance will be dropped. Weeks are counted from the official start date of the semester.

Last Date of Attendance During:	Tuition Adjustment %
Week 1	100%
Week 2	100%
Week 3	80%
Week 4	60%
Week 5	40%
Week 6	20%
Week 7 and after	0%

Note: This applies to students taking a leave of absence or officially withdrawing from the institution; for an individual course withdrawal, please refer to the Course Changes section for policy and refund information.

Audit Rate

A 50% reduced tuition rate per semester hour for the 2020-2021 academic year is available for those who wish to audit a course. Audit registration cannot be changed to credit once the semester has started.

Tuition Payments & Billing

WPI sends electronic bill statements (eBill) to the WPI email address assigned to each student. Bills are sent in the fall and spring semesters. It is important to view each new eBill you receive as changes could have occurred in your account.

Tuition must be paid in full by the specified due date on the electronic bill (eBill) statement. Students that register within one week prior to the eBill due date are required to pay at the time of registration. Students remit payment online with a checking account (no fee) or via credit card (2.75% fee). For international credit card or domestic and international wire payments visit https://www.flywire.com/school/wpi. For information on the eBill process or payment options, please visit www.wpi.edu/+bill.

Late Fees

Late fees of up to $250 will be assessed on balances and accounting holds will be placed on accounts. The first late fee is assessed after the initial due date for the bills, the second is typically assessed mid semester for outstanding balances. WPI fully supports the Veterans Benefits and Transition Act of 2018. Sec. 103 amends US code to prevent schools from penalizing Ch. 31 or 33 students if/when the VA is late making payments. WPI policy supports and agrees to the VA recommendations of the following while waiting for VA payments: WPI agrees to not prevent enrollment, charge a late penalty fee(s), require alternative or additional sources of funding or deny access to school resources

Monthly Payment Option

A monthly payment plan is available for each semester. Payments will be divided into equal monthly payments. There is an annual or semester enrollment fee for use. However, there are no additional charges or interest (late fees or returned payment fees may apply). For more information, visit Tuition Management Systems (TMS) at www.wpi.afford.com or contact the Bursar's Office at www.wpi.edu/+bill.

Health Insurance

All full-time graduate students must be covered by health and accident insurance equivalent to that offered under the WPI Student Health Insurance Plan. Students must complete a waiver form online annually if they wish to not purchase the WPI offered plan. Optional coverage for a spouse or dependent is available. Please contact the Bursar's Office www.wpi.edu/+bill for further information.

Visit us any time at: www.wpi.edu/+registrar

Degree Requirements

The following are WPI's minimum requirements for advanced degrees. The general requirements for all advanced degrees must be satisfied to earn any advanced degree. The additional requirements for specific degrees must be satisfied in order to earn the specified degree, regardless of the field in which the degree is earned. Please review department requirements for more specific information.

General Requirements for All Advanced Degrees

All degree requirements must be satisfied before the degree is awarded. Exceptions to general and specific degree requirements or to other rules may be made, but only by the Committee on Graduate Studies and Research (CGSR).[1] Requests for exceptions are to be made by written petition to that committee.

At the time the degree is awarded, the student must have been admitted to the graduate program of the degree-granting program. Administratively, a degree-granting program may be a department or a program.

A minimum of two-thirds of the required graduate credit for an advanced degree must be earned at WPI.

All degree and certificate programs require a minimum program GPA of 3.0.

In applying for graduation, the student must specify by year which graduate catalog contains the rules being satisfied. These rules may be those in place on the date of the student's matriculation, those in place on the date of the student's application for graduation, or those in place in a single graduate catalog in effect between the dates of matriculation and graduation.

After the Application for Degree is submitted, all advanced degrees are subject to the final approval of the Registrar's Office, which determines if the student has satisfied the letter and intent of the requirements for advanced degrees.

The Registrar's Office submits a candidates list to CGSR who make their recommendations for the approval of advanced degrees to the faculty of the institute, which in turn recommends to the president and trustees for their final approval the names of students who should be awarded advanced degrees.

Requirements for the Master of Business Administration and Master of Mathematics for Educators appear under the descriptions of the awarding programs.

General Requirements for the Master of Science and Master of Engineering

The student must obtain a minimum of 30 credit hours of acceptable course, thesis or project work.

If a thesis is required by the student's program, it must include at least 6 credit hours of research directed toward the thesis, in a project resulting in the completion of an M.S. thesis.

A student completing a master's degree with a thesis option is required to make a public presentation of the thesis. Departments may, at their option, extend the presentation to include a defense of the thesis.

The student must obtain a minimum of 21 credit hours of graduate level courses or thesis (18 credit hours for students in the Combined Bachelor's/Master's Program), including at least 15 credit hours of graduate level courses or thesis in the major field of the student. Other courses (to make up the minimum total of 30 credit hours) may include advanced undergraduate courses approved by the student's program. Such courses are normally considered to be those at the 4000 level. The use of advanced undergraduate courses for satisfaction of graduate degree requirements must be approved by the student's program. A 1/3-unit WPI undergraduate course taken for graduate credit is assigned 2 credit hours of graduate credit. A graduate student registered for graduate credit in an undergraduate course may be assigned additional work at the discretion of the instructor.

General Requirements for the Doctorate

The student must demonstrate to the faculty high academic attainment and the ability to carry on original independent research.

The student must complete a minimum of 90 credit hours of graduate work beyond the bachelor's degree, or a minimum of 60 credit hours of graduate work beyond the master's degree, including in either case at least 30 credit hours of research.

The student must establish residency by being a full-time graduate student for at least one continuous academic year.

The student must attain status as a doctoral candidate by satisfying specific degree requirements in the student's field.

The student must prepare a doctoral dissertation and defend it before a Dissertation Committee, at least two of whose members must be from the student's program and at least one of whose members must be from outside the student's program. After a successful defense, determined by a majority vote in the affirmative by the Dissertation Committee, the dissertation must be endorsed by those members of the Dissertation Committee who voted to approve it. The completed dissertation must follow in format the instructions published by the library (see page 22). After final approval for format of the dissertation, the Provost will notify the Registrar that the dissertation has been approved.

1 CGSR—The Committee on Graduate Studies and Research (CGSR) is concerned with all post-baccalaureate programs of the University, and reviews and recommends changes in WPI policies on goals, student recruitment, admissions, academic standards, teaching and research assistantships, scholarships and fellowships. It also makes recommendations to the faculty and administration on new graduate programs and courses, and changes in programs and courses. The committee acts on admission of graduate students to degree candidacy, dismissal for failure to meet academic standards, and student petitions on academic matters. It brings to the faculty for action the names of students whom it has determined are eligible for post-baccalaureate degrees. The committee reviews and recommends changes in policy on the funding, promotion and conduct of research at WPI.

2 GPA—The Grade Point Average (GPA) is calculated as the sum of the products of the grade points and credit hours for each registered activity, in the average, divided by the total number of credit hours for all registered activities in the average. Grade points are as follows: A = 4.0; B = 3.0; C = 2.0; D = 1.0; and F = 0.0.

Once a student has satisfied the departmental candidacy requirements, the student will be permitted to enroll for dissertation credits. Prior to completion of candidacy requirements, a student may enroll for no more than 18 credits of directed research.

General Requirements for the Combined Bachelor's/ Master's Degree Program

Only registered WPI undergraduates may enter the Combined Bachelor's/Master's Program. To enter, a student must submit an application and required support materials to WPI's Office of Graduate Admissions, preferably in the junior year. Admission to the combined program is made by the faculty of the program that awards the graduate degree. A student in the combined program continues to be registered as an undergraduate until the bachelor's degree is awarded.

While in the combined program, a student may continue to enroll in courses or projects toward the undergraduate degree; the student may also register for graduate courses, projects, directed research or thesis credits toward the master's degree.

A student in the combined program may, within the program limit and with prior approval, use a limited number of the same courses toward the bachelor's and master's degrees. The limitation is computed from the graduate credit hours for each course. Courses whose credit hours total no more than 40% of the credit hours required for the master's degree, and which meet all other requirements for each degree, may be used to satisfy requirements for both degrees. Such courses are recorded on the transcript using the credit hours/ units and grades appropriate at the graduate or undergraduate levels. For students in the combined program, approved undergraduate courses are assigned graduate credit with a conversion rate of 1/3 WPI undergraduate unit = 2 credit hours. Graduate courses applied toward the undergraduate degree are awarded undergraduate credit with a conversion rate of 1 credit hour = 1/6 undergraduate unit.

Students in the combined program may use advanced undergraduate courses to satisfy graduate degree requirements. The academic department decides which courses may be used in this way. Faculty members teaching these advanced undergraduate courses may impose special requirements.

If the programs awarding the bachelor's and master's degrees are not the same, the program awarding the graduate degree may require that the student's major qualifying project relate in some way to the graduate program's discipline. The graduate program may also make other requirements as it deems appropriate in any individual case. Additional requirements appear within each department's section in this catalog.

To obtain a master's degree via the combined program, the student must satisfy all requirements for that master's degree. To obtain a bachelor's degree via the combined program, the student must satisfy all requirements for that bachelor's degree.

The time limit for completing the combined program varies by department from one to four years. See department description for full information.

Limitation of Time to Complete Degree

Students must complete degree requirements within the following timelines:

Degree	Time Limit
Graduate or Advanced Certificate	Within 3 years of matriculation
Master's Degree (M.S., MENGR, MME)	Within 5 years of matriculation
M.B.A.	Within 7 years of matriculation
Ph.D.	Within 10 years of matriculation

Approved leaves of absence do not stop the clock for the completion of the degree. Students who require more time to complete their degree must petition the Dean of Graduate Studies to continue.

Transfers and Waivers

A student may petition to use graduate courses completed at other accredited, degree-granting institutions to satisfy WPI graduate degree requirements. A maximum of one-third of the credit requirements for a graduate degree may be satisfied by courses taken elsewhere and not used to satisfy degree requirements at other institutions.

Students should submit their petitions to their academic department or program; once they are approved they are filed with the Registrar.

To ensure that work completed at other institutions constitutes current practice in the field, a WPI program may set an expiration date on transfer credit. After this date, the course may not be counted towards a WPI degree.

Transferred courses are recorded on the student's WPI transcript with the grade CR and are not included in the calculation of grade point averages. Grades earned in Biomedical Consortium courses, however, are recorded on the transcript as if they were taken at WPI itself.

A student who withdraws from a graduate program and is later readmitted may apply courses and other credits completed before the withdrawal toward the degree. The admitting program will determine at the time of readmission which courses taken by the student may be applied toward the degree and the latest date those courses may be applied. There is no limit, other than that imposed by the program, on the number of credits a readmitted student may use from prior admissions to the same degree program.

With the appropriate background, a student may ask permission to waive a required course and substitute a specified, more advanced course in the same discipline. Requests are subject to approval by the student's program and must be filed with the Registrar within one year of the date of matriculation in the program. A program may waive (with specified substitutions) up to three required courses for a single student.

Acceptability of Credit Applicable to an Advanced Degree

Graduate level credit, obtained from courses, thesis and project work, may include:

- Coursework included in the approved Plan of Study.
- Coursework completed at the graduate level and successfully transferred to WPI from other accredited, degree-granting institutions (see Transfers and Waivers).
- Graduate coursework completed at the undergraduate level at WPI and not applied toward another degree.

A maximum of one-third of the credit requirements from one graduate degree, either completed or in progress, at WPI may be used in partial fulfillment of the requirements for another graduate degree at WPI.

No credit may be triple counted for any degree at any level of study.

Theses and Dissertations

WPI is a member of the Networked Digital Library of Theses and Dissertations. This organization is dedicated to "unlocking access to graduate education" by making the full text of theses and dissertations available online.

Students are required to submit an electronic version of their thesis or dissertation entirely through the web. Submission deadlines throughout the year are published in the Registrar's calendar, https://www.wpi.edu/offices/registrar/calendar. Students should consult with their department/program for any defense scheduling deadlines and policies, but at a minimum should plan to hold their defense no later than 3 weeks before an ETD submission deadline to allow adequate time for any ETD revisions before final submission.

Most submitted theses and dissertations will be made available to the general public via the web, but individual authors and their advisors may choose to temporarily restrict access to their works based on factors that include confidentiality and intellectual property. Students should discuss these issues thoroughly with their advisors and committee members as early in the process as possible.

The following are required for proper submission of electronic theses and dissertations (ETDs):

1 Approval Form (Signatures). This can be a scanned copy of your signed thesis signature page, or it can be a digitally signed form that includes your thesis title, degree, date, and committee members. A form for collecting digital signatures is available on the ETD submission information page. You will submit the signed Approval Form to the Registrar's Office through the eProjects submission system as you submit your thesis.

2 Your thesis or dissertation, converted to a single PDF file and uploaded via eProjects. If you have additional files or appendices, these should be added as separate supplementary files rather than submitting your thesis as a PDF portfolio. Students will receive a confirmation from the eProjects ETD submission system once it has been accepted. The Registrar's Office will be notified simultaneously of the ETD confirmation.

Extensive information about creating and submitting ETDs is available on the web at: http://www.wpi.edu/+etd

Thesis Binding

Students and departments may wish to retain a bound paper copy of theses and dissertations. Information on thesis binding can be found online at http://www.wpi.edu/+etd

Student Services

Facilities and Services

Bookstore

The bookstore, located on the second floor of the Rubin Campus Center, is open during the first days of classes from 8:00 a.m. to 7 p.m. During the rest of the school year, hours of operation are 8 a.m. to 7 p.m. Monday through Thursday, 8 a.m. to 5 p.m. Friday, and 11 a.m. to 5 p.m. on Saturday.

Textbooks for off-campus courses may be purchased at the first meeting of each course. Payment may be made by cash, check or credit card. Additionally, textbooks may be purchased online at http://wpi.bncollege.com.

For more information please call (508) 831-5247 or e-mail bkswpi@bncollege.com.

Student Health Center

In addition to purchasing health insurance, graduate students may also make use of WPI's Student Health Center for an annual fee of $370 . By choosing this option, you can have a doctor at the Center serve as your primary care physician. You may also then use the center on a walk-in basis during its normal hours (weekdays 8:00am to 5:00pm). You can learn more about WPI's Student Health Center at www.wpi.edu/+Health.

WPI Police

Personal safety information, security practices at WPI and the University's crime statistic information can be obtained by visiting the campus police Website. Students can also obtain a copy of the University's "Right To Know" brochure by contacting the WPI Police Department at 508-831-5433.

Graduate students are entitled to parking permits for an annual fee. Parking is on a first-come, first-served basis. Parking is also available on the city streets surrounding the campus. Be sure to obey parking signs, as enforcement in Worcester is strict. The city's winter parking regulations are available on the WPI police website, as well.

Decals may be purchased at the WPI Police Department located at Founders Hall in the Lower Level. WPI Police also has prepared a brochure on parking regulations that is available on-site or online at https://www.wpi.edu/offices/police/parking-traffic.

Career Development Center

The Career Development Center (CDC) at WPI assists graduate students in the development of lifelong skills related to careers and the job search process. The CDC provides resources and support to graduate students on resume/CV writing, cover letter critiques, internship and job search strategies, interviewing skills/mock interviews, advanced degree pursuit, career advising, job offer evaluation and negotiation skills, and more. Support to graduate students is available through appointments with a CDC staff member, walk-ins, and workshops. For distance students, telephone and Skype appointment options are available. The CDC is available for lifetime service and support to alumni, free of charge.

Every graduate student has a Job Finder account to search for companies and jobs, gain access to subscription resources (Career Shift, Going Global, Career Search, MyPlan), access upcoming workshops and corporate events, and more. All appointments are scheduled through Job Finder, via "Request an Appointment" in the Shortcuts menu.

Internship Resources

Resources are available at the Career Development Center (CDC) for graduate students seeking graduate internship experiences during their studies at WPI. The CDC maintains an extensive database of companies and other external organizations interested in supporting graduate students in their professional development via internships. All WPI students have access to this database, as well as the ability to apply to posted opportunities. To find out more, please contact the CDC.

To contact the CDC, call 508-831-5260, email cdc@wpi.edu, or visit us at the Project Center, Lower Level.

Class Cancellation

When all classes are cancelled (severe weather during the midday period, forecast to last through evening) cancellation will be broadcast on radio stations WTAG, WSRS, WAAF, WFTQ, WKOX and WBZ. Information will also be posted on the university website and on the cancellation hot line at 508-831-5744.

Information Technology Services

WPI Information Technology Services offers a wide range of information technology resources to the WPI community to support teaching, learning, research and student life.

Access

The WPI computer account acts as the graduate student's WPI virtual identity while the student is actively registered. Usage is governed by the Acceptable Use Policy. The account provides access to many technology resources including:

Network:

- Wired and wireless network available in all academic buildings, residence halls, and participating Greek houses
- High speed Internet connectivity including connection to Internet2
- Virtual Private Network (VPN) provides secure remote access to WPI on-campus information technology resources
- Information Security monitors the WPI network and provides data malware protection

University Systems:

- University services, such as email, learning management system, eProjects, web site, software applications, remote desktop, databases, etc. are enabled by System Operations and Web Development teams.
- Enterprise-wide technology solutions such as Banner, Workday, and their related data systems, enable administrative departments to run the critical business functions of the University. They provide students and faculty access to student registration, advising, and financial information. They also enable students to update their biographical information, set proxy, and check grades online.

Software

Students can access numerous software applications including academic courseware:

- in public computer labs
- via remote services
- via network download for some applications
- discounted purchase via online store

Computer Labs

Over 700 public computers are available across campus for student use. Many are located in open access labs within academic buildings and throughout the Gordon Library. Public computer labs offer a consistent user interface and software profile. Specialty labs for students include:

- Multimedia Lab and Shuster Digital Scholarship Lab enabling high-end digital editing, scanning, and GIS are available in the Gordon Library
- Maker space, prototyping and recording labs are housed in the Foisie Innovation Studio
- Design Studio offers powerful workstations for CAD/FEA/FEM projects and coursework in Higgins Labs

Printing Services

The Gordon Library Information Commons Print Center is available to meet students' scanning and printing needs. Printers are also located throughout the Gordon Library as well as within some computer labs. For additional printing services listed below see Technology Support and Instruction:

- Large-format poster printing
- Rapid prototyping/3D printing

Collaboration and Learning Resources

Collaboration and learning are supported through specialized software and applications, technology-enhanced spaces, and equipment loans.

- Learning Management Software: Canvas course web sites
- Tools: Office 365 (email/calendar/contact, task, document management), Microsoft Teams for video/audio and chat
- Web-conferencing: Zoom allows remote participants to conduct meetings in real-time in a web-based environment from any location with a web-enabled device and a high speed Internet connection
- Tech Suites: Technology-enhanced meeting spaces with wireless screensharing designed for student project group use
- Learning Spaces: Active learning classrooms, electronic classrooms, and electronically enabled conference rooms
- Equipment Loans: Laptops, digital cameras, audio recorders, hard drives, projectors, etc.

Technology Support and Instruction

Technology Service Desk

Gordon Library, Main Floor; (508) 831-5888; its@wpi.edu; https://hub.wpi.edu

- In-person technology support provided at the Service Desk
- Requests for assistance can be submitted via phone, email or web
- IT Service, Software, and Knowledge Catalog provides answers to common issues

Academic Technology Center

Fuller Labs, Room 117; (508) 831-5220; atc@wpi.edu

- In-person technology support on audio-visual equipment loaned out for multi-media projects and campus events sponsored by WPI student organizations
- Large-format poster printing

Academic and Research Computing

Higgins Labs, https://www.wpi.edu/research/resources/support/academic-research-computing

- Instructor-led scientific and engineering software applications training
- Data management and access to cloud collaboration space
- Numerous high performance computational resources available for student research projects
- Large-format poster printing located in Higgins Labs
- Enterprise level rapid prototyping/3D printing located in Higgins Labs

Gordon Library

The George C. Gordon Library is open over one hundred hours each week during the academic year. The library provides resources and innovative services in support of teaching, learning and scholarship at WPI.

The library's collections support the curriculum and research needs of the WPI community. The library offers an extensive collection of print and electronic journals, over 700,000 academic ebooks, and several hundred research databases which support all areas of the WPI curriculum. The library collection also contains undergraduate project reports, and graduate theses and dissertations, with those from recent years available online. Music CDs, DVDs and other media, and bestsellers and newspapers are available for educational and recreational purposes. The library's Archives and Special Collections department includes the historic records and artifacts of the university, rare books, manuscripts, and artwork including major holdings of Charles Dickens's life and works; and a growing archive that documents WPI's history of invention and innovation in education and industry.

The library catalog, electronic journal and book collections, specialized research databases, course-specific information, and many other resources are available from the library's website (http://library.wpi.edu). The website features powerful search options and links to digital resources and services. Access to WPI users who are off-campus is available by logging into resources through the WPI proxy service. This can be done through the library's website or by following instructions available at: https://www.wpi.edu/library/research/research-off-campus.

The staff of Gordon Library offers many services that support graduate students. Librarians can meet with students either as individuals or in groups for research consultations. Meetings can be scheduled via the library's website, or by emailing library@wpi.edu, and librarians are available to meet with remote learners via video conferencing software. Librarians also support graduate students in their roles as teaching assistants by providing library instruction and orientation sessions.

The staff of Archives and Special Collections works with students to access historical resources relating to WPI and the region.

Students can request any materials not held in Gordon Library through the interlibrary loan service. Requested journal articles can often be delivered electronically within a day or less.

WPI students also have access to the collections of other academic libraries within Central Massachusetts with the library's membership in the Academic and Research Collaborative (ARC). Students can obtain an ARC cross-borrowing card (available at the library's front desk) which allows direct borrowing at many regional academic libraries.

Gordon Library information services, the Academic Technology Center, and the Technology Service Desk are conveniently co-located on the library's main floor. The adjacent Class of 1970 Library Café serves food and beverages, is open 8 am - 10 pm (M - F) and limited weekend hours, and follows the undergraduate academic year calendar.

The library's four floors contain a wide variety of individual and group study spaces. Tech Suites – collaborative work areas equipped with up-to-date screen-sharing technology – can be reserved for student group use. Additional group study spaces are located throughout the building, among them Studio@Gordon, an active and informal collaboration space on the ground floor. There are also computer workstations configured for group and individual use, many with large monitors for collaborative project work. The Multimedia Lab on the first floor offers specialized multimedia and GIS software and scanners. Adjacent to the Multimedia Lab are the Shuster Digital Scholarship Lab and the Anderson Lab. The Shuster Digital Scholarship Lab is equipped with scanning equipment, a document camera, collaborative work tables, projection screens, and six Dell Surface Studio 2 computer workstations. The Shuster Digital Scholarship Lab and the Anderson Instruction Lab can be used by student groups during evenings and weekends, and on weekdays when not booked for WPI training or course-related events. The library features both wireless and wired computer network access, and over 100 public-use computers.

Special exhibits including exhibits of work by WPI artists are offered regularly in the library's galleries, and WPI authors are regularly invited to talk about their work in the library's Meet the Author series. For more information please visit the library website at http://library.wpi.edu.

Housing

Most graduate students live in rooms or apartments in residential areas near the campus. A limited amount of on-campus housing may be available for single graduate students. Family housing is not available on campus.

The Office of Residential Services, 508-831-5645, provides information regarding both on-campus and off-campus housing. A listing of off-campus accommodations is available at www.wpi.edu/Admin/RSO/Offcampus/.

International Graduate Student Services

The Office of International Students and Scholars is located at WPI's International House at 28 Trowbridge Road. The office provides information and assistance on immigration and other regulatory matters, information on cultural and social programs and services, as well as general counseling.

With 1,472 international students from 85 countries (Fall semester, 2015), WPI is the embodiment of the diversity that characterizes the United States. The House serves as a venue for a variety of programs throughout the year, such as coffee hours, movies, Midnight Breakfast, lectures and other social and cultural activities. The House, which provides wireless access to the network, has several facilities available to students and scholars and student groups interested in international issues, including:

- International Seminar Room for discussion groups, meetings and ESL classes
- International Resources Room with cross-cultural material, travel information and ESL materials as well as computer access
- lounge for students and visitors to relax and enjoy a cup of coffee or a game of backgammon
- two guest rooms for temporary housing

Office of International Students and Scholars: 508-831-6030. ESL Director: 508-831-6033.

Mail Services

Located in the Campus Center, first floor. Student Mail Room 508-831-5317, Incoming/Receiving 508-831-5523, Mail Processing 508-831-5317.

- Package pick-up
- Stamps sold
- Letters and packages weighed, metered
- Discounted Express Mail
- Fax services
- Limited number of mailboxes available

Printing Services

Located in Boynton Hall, lower level. Telephone 508-831-5842 or -5571. Hours (Monday through Friday) 8 a.m. to 4:30 p.m.

- Offset printing
- Photocopying (including color)
- Binding of reports
- Laminating
- Print from disc, electronically sent files or hard copy

Sports and Recreation

The university provides a varied program of sports and recreation. Graduate students usually enter teams in several intramural sports and may participate in certain intercollegiate club sports as well as on-campus musical or theater groups.

The NEW Sports and Recreation Center presents an opportunity for the whole WPI community to be more active and practice healthier lifestyles.

The Sports and Recreation facilities includes a two-story fitness center with cardio equipment and free weights, a four-court gymnasium, a competition pool, dance studios, a three-lane jogging track, racquetball and squash courts. Graduate students frequently join faculty groups for noontime jogging, aerobics and basketball.

A wide variety of entertainment is brought to the campus, ranging from small informal groups to popular entertainers in the 3,500-seat Harrington Auditorium. A series of films is shown in Perreault Hall, and chamber concerts are presented in the Baronial Hall of Higgins House.

The normal social activities of a medium-sized city are readily accessible, many within easy walking distance. Other activities of interest to students are offered by the many colleges in the Worcester Consortium.

Student ID Cards

The WPI ID is also a student's library card and is used in many departments for lab access as well.

Students may also deposit money on their cards for use in the WPI dining locations at a 10% discount. The ID office is located in East Hall. The hours are: Monday through Friday 8 a.m. to 5 p.m. For information, call 508-831-5150.

Dean of Graduate Studies

The Dean of Graduate Studies is the principal advocate for graduate programs across all disciplines at WPI. Graduate students needing assistance with academic issues should reach out to the Dean's Office. The Dean manages offers of funding for graduate Teaching Assistants (TAs), Research Assistants (RAs), and graduate fellowships, oversees the distribution of graduate TAs, coordinates the annual graduate student orientations, and other major events for graduate students, including Graduate Research Innovation Exchange, the i3 Competition, the Fellowship Recognition Dinner, Student Training and Readiness Sessions (STARS), the Graduate Student Travel Fund, the PhD Global Research Experience, and other graduate student professional development activities. In addition, the Dean serves as the chief academic advisor to the Graduate Student Government.

Dean of Students

The Dean of Students' office staff is available to students enrolled in all programs to assist with any out-of-the-classroom concerns that may arise. Staff members are available between 8:30 a.m. and 5 p.m. Appointments outside of these hours can be arranged by calling 508-831-5201.

Return to Table of Contents

Faculty

Nikolaos A. Gatsonis, Professor and Program Director; Ph.D., Massachusetts Institute of Technology. Continuum and atomistic computational methods for fluids and plasmas, development of plasma diagnostics and microfluidic devices, spacecraft propulsion and micropropulsion, spacecraft/environment interactions.

John J. Blandino, Associate Professor and Undergraduate Coordinator; Ph.D., California Institute of Technology. Fluid mechanics and heat transfer in microdevices, plasma diagnostics, electric and chemical propulsion, propulsion system design for precision formation flying.

Raghvendra Cowlagi, Associate Professor; Ph.D., Georgia Institute of Technology. Autonomous mobile vehicles, motion planning and optimal control, hybrid optimal control with applications in aerospace engineering, formal methods for system safety and reliability.

Michael A. Demetriou, Professor and Graduate Coordinator; Ph.D., University of Southern California. Control of intelligent systems, control of fluid-structure interaction systems, fault detection and accommodation of dynamical systems, acoustic and vibration control, smart materials and structures, sensor and actuator networks in distributed processes, spacecraft attitude estimation and control.

Jagannath Jayachandran, Assistant Professor; Ph.D., University of Southern California. Combustion at engine-relevant thermodynamic conditions; ignition, propagation, and extinction of flames; transient phenomena in reacting flows; air-breathing propulsion; detailed modeling of low-dimensional reacting flows; optical and laser-based diagnostics.

Nikhil Karanjgaokar, Ph.D., University of Illinois at Urbana-Champaign: Experimental mechanics at micro/nano-scale, temperature and rate dependent mechanics of nanostructured materials, dynamic response and flow of granular media, mechanics and damage of inhomogeneous materials, optical measurement techniques.

David J. Olinger, Associate Professor, Ph.D., Yale University. Fluid mechanics, aero and hydrodynamics, fluid structure interactions, fluid flow control, renewable energy.

Mark W. Richman, Associate Professor, Ph.D., Cornell University. Mechanics of granular flows, powder compaction, powder metallurgy.

Zachary Taillefer, Assistant Teaching Professor. Ph.D. Worcester Polytechnic Institute. Electric Propulsion; Plasma Diagnostics.

Zhanxian Yuan, Assistant Professor, Ph.D., Georgia Tech. Aerospace structures, composite structures, structural dynamics.

Programs of Study

The Aerospace Engineering offers three graduate programs of study with the following degree options:

- The Master of Science (M.S.) program leading to the M.S. degree.
- The combined Bachelor of Science (B.S.)/Master of Science Program leading to the B.S. and M.S. degrees.
- The Doctor of Philosophy (Ph.D.) program leading to the Ph.D. degree.

Admission Requirements

For the M.S. program, applicants should have a B.S. in aerospace engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.). The requirements are the same for admission into the thesis and non-thesis options of the M.S. program. At the time of application to the master's program, the student must specify his/her thesis option (thesis or non-thesis).

For the combined B.S./M.S. program, students must be currently enrolled as WPI undergraduates in aerospace engineering or in a related engineering field. When applying to the B.S./M.S. program, students must specify their intention to pursue either the thesis or non-thesis M.S. option.

For the Ph.D. program, a B.S. or M.S. degree in aerospace engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.) is required. The Aerospace Engineering Program reserves its financial aid for graduate students in the Ph.D. program or in the thesis option of the M.S. program.

Degree Requirements

The AE degrees are based on a graduate curriculum which is composed of three areas of study: Fluids and Propulsion; Materials and Structures; Dynamics and Controls. Each area of study consists of a Core and Breadth component as shown in Table 1.

Table 1: Core and Breadth Areas of Study in AE

Fluids and Propulsion

Core

AE 5101/ME 5101. Fluid Dynamics (2 credits) or

AE 5107/ME 5107. Applied Fluid Dynamics

AE 5106. Air Breathing Propulsion (2 credits) or

AE 5111. Spacecraft Propulsion (2 credits)

Breadth

AE 5102. Advanced Gas Dynamics (2 credits)

AE 5105/ME 5105. Renewable Energy (2 credits)

AE 5108/ME 5108. Introduction to Computational Fluid Dynamics

AE 5110. Introduction to Plasma Dynamics (2 credits)

AE 6108/ME 6108. Intermediate Computational Fluid Dynamics (2 credits)

Return to Table of Contents

Dynamics and Control

Core

AE 5223. Space Vehicle Dynamics and Control (2 credits) or

AE 5224. Air Vehicle Dynamics and Control (2 credits)

AE 5220/ME 5220. Control of Linear Dynamical Systems (2 credits)

Breadth

AE 5221/ME 5221. Control of Nonlinear Dynamical Systems (2 credits)

AE 5222. Optimal Control of Dynamical Systems (2 credits)

Materials and Structures

Core

AE 5383. Composite Materials (2 credits)

AE 5380/ME 5380. Foundations of Elasticity (2 credits) or

AE 5381/ME 5381. Applied Elasticity (2 credits)

Breadth

AE 5382. Aeroelasticity (2 credits)

M.S. Degree

The Master of Science degree requires the completion of 30 graduate credit hours. Students may complete up to 8 credits of directed research (AE 5098).

The distribution of credits is as follows:

- 18 graduate credits in AE courses, with a minimum of 2 credits in each of the three AE Core Areas of Study (includes a maximum of 8 credits of directed research – AE 5098)
- 8 graduate credits of free electives in or outside AE
- 3 graduate credits in applied mathematics (MA 4551, MA 4733, MA 4631, MA 4632, MA 501, MA 507, MA 511, MA 514, MA 521 or any other course with the approval of AE graduate committee)
- 1 graduate credit in the Graduate Colloquium in Aerospace Engineering (AE 5090)

TOTAL 30 Credits

Prior to registering for directed research AE 5098, the student must have completed at least 6 graduate credits in AE courses.

Academic Advising

The schedule of academic advising ensures that students are well advised throughout the program.

Temporary Advisor: upon admission to the M.S. program each student is assigned or may select a Temporary Advisor. Arranges an academic plan covering the first 8 credits of prior to the first registration.

Academic Advisor: elected by a student prior to registering for more than 8 credits. Arranges an academic plan covering the remaining course of study.

The Combined B.S./M.S. Program

The AE Program offers a combined B.S./M.S. program for currently enrolled WPI undergraduates. The M.S. degree requires the completion of 30 graduate credit hours.

For students admitted in the B.S./M.S. program, a maximum of 8 graduate credits may be counted toward both the undergraduate and graduate degrees. Double-counted graduate credits must be in courses, including graduate-level independent study and special topics. A maximum of four (4) credits can be double-counted in courses from Engineering, Basic Science or Mathematics which must be at the 4000-level. A grade of B or better is required for any course to be counted toward both degrees.

Acceptance into the B.S./M.S. program means that the candidate is qualified for graduate school, and signifies approval of the graduate courses listed for credit toward both the undergraduate and graduate degrees.

Ph.D. Degree

Students are admitted to the Ph.D. program and must retain a full-time status up to admission to Candidacy granted by successfully passing the AE 6999 Ph.D. Qualifying Examination.

The course of study leading to the Ph.D. degree in aerospace engineering requires the completion of 90 credits beyond the bachelor's degree, or 60 credits beyond the master's degree.

For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

- 30 graduate credits in coursework
  - 16 graduate credits in AE courses (incl. Special Topics and ISP)
  - 8 graduate credits in courses in or outside of AE
  - 3 graduate credits in applied mathematics (MA 4551, MA 4733, MA 4631, MA 4632, MA 501, MA 507, MA 511, MA 514, MA 521 or any other course with the approval of AE graduate committee)
  - 3 graduate credits in the Graduate Colloquium in Aerospace Engineering (AE 5090)
- 30 graduate credits in Dissertation Research (AE 6099)
- 30 graduate credits in
  - Additional coursework
  - Additional Dissertation Research (AE 6099)
  - Supplemental Research (AE 5098, AE 6098)
- 0 credits in AE 6999 Ph.D. Qualifying Examination

TOTAL 90 credits

For students proceeding from Master's to Ph.D. degree, the 60 credits should be distributed as follows:

- 12 graduate credits in AE courses (incl. Special Topics and ISP)
- 30 graduate credits in Dissertation Research (AE 6099)
- 16 graduate credits in
  - courses in or outside of AE
  - Dissertation Research (AE 6099)
  - Supplemental Research (AE 5098, AE 6098)
- 2 graduate credits in the Graduate Colloquium in Aerospace Engineering (AE 5090)
- 0 credits in AE 6999 Ph.D. Qualifying Examination

TOTAL 60 credits

Prior to admission to Candidacy, a student may receive up to 18 credits of pre-dissertation research under AE 6098. Only after admission to Candidacy with the successful passing of AE 6999 may a student receive credit toward Dissertation Research under AE 6099. The result of the dissertation research must be a completed doctoral dissertation.

Academic Advising and Schedule

Temporary Advisor

Upon admission to the Doctoral Program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 8-10 credits of study. This plan should be arranged before the first day of registration.

Dissertation Advisor and Plan of Study

A student selects an AE Dissertation Advisor who agrees upon prior to registering for more than 8-10 credits. The Dissertation Advisor will approve the Plan of Study which includes the Dissertation Topic.

Ph.D. Qualifying Exam and Admission to Candidacy

Admission to Candidacy will be granted when the student has satisfactorily passed the written AE 6999 Ph.D. Qualifying Exam. If a student fails to earn a Pass in all three Core Areas of Study of the Qualifying Exam the student must withdraw from the Ph.D. program by end of D term of the year of the Qualifying Examination. The details of the examination procedure are arranged by the Aerospace Engineering Office.

Dissertation Committee and Dissertation Proposal

Formed prior to registering for more than 18 credits and after Admission to Candidacy. The Dissertation Committee consists of the Dissertation Advisor, at least one core faculty of the Aerospace Engineering Program, and at least one outside member.

Each Doctoral Candidate must prepare a brief written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to date. The Dissertation Proposal must be made within a year after the Qualifying Exam and admission to candidacy. Both the written and oral parts of the Proposals are presented to members of the Dissertation Committee and a representative from the AE Graduate Committee. The prepared portion of the oral presentation should not exceed 40 minutes, and up to 60 minutes should be allowed for discussion. If the members of the Dissertation Committee and the Graduate Committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, then the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 35 minutes allowed for discussion. Students can continue their research only if the Dissertation Proposal is approved. If the Dissertation Proposal is not approved, the Doctoral Candidate may find a new Dissertation Advisor and proceed with a new Dissertation Proposal.

Dissertation Defense

Each Doctoral Candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the Dissertation Committee and a representative of the AE Graduate Committee who is not on the Dissertation Committee. The defense is open to public participation and consists of a one-hour presentation followed by a one-hour open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the aerospace engineering graduate program secretary. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

Laboratories and Facilities

Aerospace Engineering MQP Laboratory

HL005 (AE Faculty)

This 450 sq. ft. facility supports Major Qualifying Project work associated with a number of different aerospace related projects. Workbenches provide the space required for assembly, integration, and testing of hardware, often with more than one student group working together on complex, interrelated projects.

Aerodynamics Test Facility

HL016 (Olinger)

This 975 sq. ft. laboratory houses a low-speed, closed-return wind tunnel, with a test-section of 2'′2'′8'. The tunnel speed is continuously variable up to 180 ft/s. The temperature in the tunnel can be controlled via a controller and a heat exchanger in the settling chamber. The tunnel is equipped with a two-component dynamometer. Aerodynamic flows are studied in this laboratory with the aid of traditional pressure, temperature, and velocity sensors, as well as advanced optical instrumentation. The test facility is used for graduate research and undergraduate projects.

Laboratory for Fluids and Plasmas

HL016, HL313 and HL314 (Blandino, Gatsonis)

The Laboratory for Fluids and Plasmas (LFP) supports research and educational activities in electric and chemical micropropulsion, plasma diagnostics, and microfluidics.

The LFP-016 covers 450 sq. ft and houses a 50 inch diameter, 72 inch long stainless steel vacuum chamber (T2), which enables the characterization of electric and chemical thruster component performance. The pumping system for T2 includes a rotary mechanical pump, positive displacement blower combination capable of providing substantial pumping speed (> 560 liters/sec) at low vacuum (10^{-2} - 10^{-3} torr). This pump pair can be used for tests requiring relatively high mass flow rates, such as plume measurements on micro-chemical thrusters. For tests of electric thrusters where lower pressures (higher vacuum) are required, a 20 inch cryopump is available which can provide up to 10,000 liters/s (on N_2) at pressures in the low 10^{-6} torr range. A second, medium-sized vacuum chamber (T4), consists of a 29.75 inch diameter, 34.25 inch tall stainless steel bell-jar. T4 uses a Leybold TurboVac 361 turbomolecular pump backed by a Leybold Trivac D16B rotary-vane dual-stage mechanical pump. The turbopump is rated for a pump speed of 350 L/s on air at pressures in the low 10^{-6} torr range. Both T2 and T4 are equipped with multiple ports for electrical and optical access. The LFP is also equipped with a variety of ancillary instrumentation including power supplies and oscilloscopes as well as data acquisition and flow delivery hardware.

The LFP in HL313-314 covers 600 sq. ft. It houses two vacuum chambers and specialized test facilities for the investigation of onboard micropropulsion, electrospray sources (for both propulsion and nano-fabrication applications), plume/spacecraft interactions, microsensors, and microfluidics. The first chamber (T1) is an 18 inch diameter, 30 inch tall stainless steel bell-jar equipped with a 6 inch diffusion pump backed by a 17 cfm mechanical pump. The system is capable of an ultimate pressure in the low 10^{-6} torr range. The second vacuum chamber (T3), is a 22.5 inch diameter, 32 inch tall stainless steel bell-jar. It is equipped with a 6-inch diffusion pump backed by a Varian DS 602 dual stage rotary vane pump. The system is capable of achieving an ultimate pressure in the 10^{-6} torr range. T3 also includes a computer controlled probe positioning system. The system consists of micos linear (VT-80) and rotary (DT-80) computer-controlled stages to achieve precise, three degree-of-freedom positioning. In addition, T3 is equipped with a 3-centimeter Kauffman Ion Source with computer-controlled, mass flow delivery. For microfluidics research, the LFP includes equipment for studies of two-phase flows in microchannels. Imaging equipment for these flows includes a high-resolution monochrome progressive scan Pulnix-1325 camera with computer based image-capture and processing software. In addition, a portable fume hood work space is available for use in testing of dielectrophoretic flows with high vapor-pressure fluids. The LFP-314/313 includes a variety of tools and specialized instrumentation including a syringe pump, oscilloscopes, precision source meter, electrometer, and digital multimeters. Data from these instruments can be collected and stored on computer using a LabView based data acquisition system.

Computational Fluids and Plasmas Laboratory

HL236 (Gatsonis)

This 660 sq. ft. computational facility is used for graduate research and educational activities in computational methods and their applications to fluids, gases, and plasmas. CFPL provides students with access to Direct Simulation Monte Carlo, Particle-in-Cell, fluid dynamics, and MHD codes as well as visualization and data reduction software.

Fluid Dynamics Laboratory

HL311 (Olinger)

This 420 sq. ft. laboratory is used for research and educational activities in fluid dynamics. It houses a low speed, low turbulence wind tunnel facility with a one-foot square test section which is used for experiments on low Reynolds number aerodynamics related to biologically inspired flight, and fluid-structure interaction. These systems are of practical importance in many aero- and hydrodynamic systems, such as micro-air vehicles and flow-induced vibration of flexible cables Standard equipment such as vibration shakers, hot-wire anemometry systems, spectral analyzers, digital oscilloscopes and data acquisition systems are also used in the laboratory.

Combustion Research Laboratory

HL311 (Jayachandran)

The Combustion Research Laboratory (CRL) is used for fundamental research and educational activities in laminar as well as turbulent, high activation energy reacting flows of relevance to aerospace propulsion and power generation. CRL is equipped with high pressure combustion facilities, high speed imaging, and laser based diagnostics.

Structures and Materials Laboratory

HL028, HL305 (Karanjgaokar)

The structures and material laboratory is used for undergraduate and graduate research in field of mechanics of novel materials and structures used in aerospace systems. The laboratory is equipped with NI Compact DAQ acquisition system for actuation and sensing applications to understand the mechanics of structures and materials. The laboratory includes an optical microscopy suite to visualize the full-field deformation of nanostructured materials with nanoscale resolution using Digital Image Correlation (DIC). The laboratory also hosts a high speed imaging system to investigate the mechanics of granular media under dynamic loading and the flow of granular media. The laboratory also focusses on the dynamic response of granular media and inhomogeneous materials using a gas-gun based impact testing setup. The laboratory is equipped with a Laser Scanning Doppler Vibrometer system to measure the velocity of vibrations in structures like particle dampers and ferroelectrics in low and high frequency ranges.

Laboratory for Intelligent Systems and Control

HL312 (Demetriou)

The (Laboratory for Intelligent Systems and Control) is a 400 sq. ft. facility equipped for experiments in control of unmanned aerial vehicles, wheeled robots, submersible vehicles, spacecraft, and dynamical systems with flexible structures. Workbenches equipped with power supplies, amplifiers, signal generators, data acquisition systems, and oscilloscopes are provided. For experiments in vehicle autonomy, state-of-the-art microcontroller platforms, such as the Raspberry Pi 2, along with sundry electronic components are available for rapid prototyping and implementation of onboard vehicle control systems. A network of off-the-shelf radio-controlled vehicle platforms such as the IRIS quadrotor helicopters are available. A network of wirelessly-controlled autonomous mobile robots such as the Clearpath Husky A200 UGV with onboard computer, IMU, and Velodyne LIDAR, the TurtleBot with LIDAR, and the iRobot Create wheeled robots are available. For experiments in control and optimization of flexible structures, an active vibration isolation table, velocity sensors, accelerometers, piezoceramic patches for actuation and sensing and a dSPACE® ACE1103 real-time data acquisition and control package are available.

Return to Table of Contents

Autonomy, Controls, and Estimation Laboratory

HL311b (Cowlagi)

The Autonomy, Controls, and Estimation (ACE) Laboratory is a 400 sq. ft. facility equipped for experiments related to motion planning and control of autonomous mobile vehicles in unknown or uncertain environments. The lab is home to a portable Vicon motion capture system consisting of 8 Vicon Vero 2.2 cameras with heavy duty tripod mounts. The motion capture system provides localization with a 1mm accuracy. The lab also provides other highly portable localization systems: a Pozyx wifi-based system and a Polhemus radio-based system. Workbenches equipped with power supplies, amplifiers, signal generators, data acquisition systems, and oscilloscopes are available. Several microcontroller platforms such as the Nvidia Jetson and Jetson Nano, aerial vehicle autopilot and remote control hardware, and sundry electronic components are available for rapid prototyping and implementation of onboard vehicle control systems. A multitude of off-the-shelf radio-controlled aerial vehicle and wheeled robotic vehicle platforms are available..

Aerospace Engineering Discovery Classroom

HL216 (AE Faculty)

In the Discovery Classroom, the traditional lecture hall is redefined to combine a multi-media classroom and an adjoining experimental 570 sq. ft. laboratory. The capabilities of the classroom allow us to use an integrated analytical – numerical – experimental approach to aerospace engineering in fludis, propulsion, materials and structures courses. We have designated the approach using this facility as the DIANE philosophy: **D**aily **I**ntegration of **A**nalytical, **N**umerical, and **E**xperimental methods into aerospace engineering classes. In a typical application, experimental apparatus are demonstrated directly in class during an engineering lecture. Real-time quantitative data are acquired from the apparatus, and the data are analyzed and compared to concurrently developed theory by the students in class. The lab includes a portable wind tunnel, a portable water tunnel, a buckling apparatus, a shear center apparatus and various other setups.

Course Descriptions

All courses are 3 credits unless otherwise noted.

Fluids and Propulsion

AE/ME 5101. Fluid Dynamics

(2 credits)

This course presents the following fundamental topics in fluid dynamics: concept of continuum in fluids; kinematics and deformation for Newtonian fluids; the mass conservation equation, momentum and energy equations for material volumes and control volumes; the differential form of mass conservation, momentum and energy equations. This course covers also applied topics chosen from: unidirectional steady incompressible viscous flows; unidirectional transient incompressible viscous flows; lubrication flows similarity and dimensional analysis. This is an introductory graduate-level course and may be taken independent of AE 5107/ME 5107.

AE 5102. Advanced Gas Dynamics

(2 credits)

An introduction to kinetic theory of gases and its application to equilibrium flows and flows with chemical, vibrational and translational nonequilibrium. Topics in kinetic theory also include the Boltzmann Equation and its relation to the continuum equations of gas dynamics. A major focus of the course is exploring how results for equilibrium flow of a perfect gas (e.g. flows in nozzles, normal and oblique shocks, expansion waves) are modified for an imperfect gas with nonequilibrium. The models of flow with nonequilibrium are then applied to the study of different flows of engineering interest including hypersonic flows (e.g. re-entry vehicles), propagating shock waves (explosions), and chemically reacting flows.

AE/ME 5104. Turbomachinery

(2 credits)

This course is an introduction to the fluid mechanics and thermodynamics of turbomachinery for propulsion and power generation applications. Axial and centrifugal compressors will be discussed as well as axial and radial flow turbines. Analysis of the mean line flow in compressor and turbine blade rows and stages will be discussed. The blade-to-blade flow model will be presented and axisymmetric flow theory introduced. Three-dimensional flow, i.e. secondary flows, will also be discussed. Students cannot receive credit for this course if they have taken the Special Topics (ME 593H) version of the same course.

AE/ME 5105. Renewable Energy

(2 credits)

The course provides an introduction to renewable energy, outlining the challenges in meeting the energy needs of humanity and exploring possible solutions in some detail. Specific topics include: use of energy and the correlation of energy use with the prosperity of nations; historical energy usage and future energy needs; engineering economics; electricity generation from the wind; wave/ocean energy, geo-thermal and solar-thermal energy; overview of fuel cells, biofuels, nuclear energy, and solar-photovoltaic systems and their role and prospects; distribution of energy and the energy infrastructure; energy for transportation; energy storage. Pre-requisites; ES 3001, ES 3004 or equivalents.

AE 5106. Air Breathing Propulsion

(2 credits)

This course covers at the introductory graduate level the design and performance of air-breathing propulsion engines. Topics covered will be chosen from: jet propulsion theory, gas turbine, ramjet, scramjet, gas dynamics of inlet and nozzle flows, component matching, thermodynamic cycle analysis of the propulsion systems, and combustion control in propulsion systems.

AE/ME 5107. Applied Fluid Dynamics

(2 credits)

This course presents applications of incompressible and compressible fluid dynamics at an introductory graduate level. Topics are chosen from: potential flows; boundary layers; vorticity dynamics and rotating flows; aerodynamics; introduction to turbulence; micro/nano flows. This course can be taken independent of AE 5101/ME 5101.

AE/ME 5108. Introduction to Computational Fluid Dynamics

(2 credits)

The course provides the theory and practice of computational fluid dynamics at an entry graduate level. Topics covered include: classification of partial differential equations (PDEs) in fluid dynamics and characteristics; finite difference schemes on structured grids; temporal discretization schemes; consistency, stability and error analysis of finite difference schemes; explicit and implicit finite differencing schemes for linear hyperbolic, parabolic, elliptic, and non-linear PDEs in fluid dynamics; direct and iterative solution methods for algebraic systems. The course requires completion of several projects using MATLAB.

AE 5110. Introduction to Plasma Dynamics

(2 Credits)

The course introduces concepts of partially ionized gases (plasmas) and their role in a wide range of science and engineering fields. Fundamental theory includes topics in: equilibrium of ionized gases and kinetic theory; motion of charged particles in electromagnetic fields; elastic and inelastic collisions, cross sections and transport processes; fluid theory and magnetohydrodynamic models; sheaths. Applications cover areas such as plasma diagnostics, plasma discharges, spacecraft/environment interactions, and plasma-aided material processing.

Return to Table of Contents

AE 5111. Spacecraft Propulsion
(2 Credits)
This course provides students with the background and theory needed to evaluate the performance of the most commonly used electric and chemical spacecraft propulsion systems. Electrostatic ion and Hall thruster theory, design, and operation are covered including theory and operation of hollow cathodes, plasma generation and ion acceleration (including design of ion optics), magnetic field design, and beam neutralization. Topics in chemical propulsion include bipropellant and monopropellant chemistry (adiabatic flame temperature and ideal performance) with a focus on catalyst-bed and nozzle design considerations. Discussion of each class of thruster will be supplemented with specific examples of flight hardware.

AE/ME 6108. Intermediate Computational Fluid Dynamics
(2 credits)
The course presents computational methods for incompressible and compressible viscous flows at an intermediate level. Topics are chosen from: grid generation techniques; finite volume schemes; stability analysis; artificial viscosity; explicit and implicit schemes; flux-vector splitting; monotonic advection schemes; multigrid methods; particle-based simulation methods. (Prerequisite: fluid dynamics; an introductory course in numerical methods for partial differential equations; programming language experience) Students who have received credit for AE/ME 5103 will not receive credit for AE/ME 6108.

Dynamics and Control

AE/ME 5220. Control of Linear Dynamical Systems
(2 credits)
This course covers analysis and synthesis of control laws for linear dynamical systems. Fundamental concepts including canonical representations, the state transition matrix, and the properties of controllability and observability will be discussed. The existence and synthesis of stabilizing feedback control laws using pole placement and linear quadratic optimal control will be discussed. The design of Luenberger observers and Kalman filters will be introduced. Examples pertaining to aerospace engineering, such as stability analysis and augmentation of longitudinal and lateral aircraft dynamics, will be considered. Assignments and term project (if any) will focus on the design, analysis, and implementation of linear control for current engineering problems. The use of Matlab®/Simulink® for analysis and design will be emphasized. (Recommended background: Familiarity with ordinary differential equations, introductory control theory, fundamentals of linear algebra, and the analysis of signals and systems is recommended. Familiarity with Matlab® is strongly recommended.)

AE/ME 5221. Control of Nonlinear Dynamical Systems
(2 credits)
Overview of stability concepts and examination of various methods for assessing stability such as linearization and Lyapunov methods. Introduction to various design methods based on linearization, sliding modes, adaptive control, and feedback linearization. Demonstration and performance analysis on engineering systems such as flexible robotic manipulators, mobile robots, spacecraft attitude control and aircraft control systems. Control synthesis and analysis is performed using Matlab®/Simulink®. (Prerequisites: Familiarity with ordinary differential equations, introductory control theory at the undergraduate level, fundamentals of linear algebra. Familiarity with Matlab® is strongly recommended.)

AE 5222. Optimal Control of Dynamical Systems
(2 Credits)
This course covers the synthesis of optimal control laws for linear and nonlinear dynamical systems. Necessary conditions for optimal control based on the Pontryagin Minimum Principle will be introduced, and cases of fixed and free terminal time and boundary conditions will be discussed. Feedback optimal control will be discussed, and the Hamilton-Jacobi-Bellman equation will be introduced. The special case of linear quadratic optimal control will be discussed. Examples throughout the course will be based on air- and space vehicle applications, such as flight trajectory optimization. Assignments and term project (if any) will introduce basic numerical techniques, and introduce software packages for optimal control. (Prerequisites: Fluency with the theory of linear dynamical systems and control is required. Familiarity with MATLAB. Familiarity with air- and space vehicle dynamics is beneficial, but not necessary.)

AE 5223. Space Vehicle Dynamics and Control
(2 Credits)
Overview of spacecraft rotational motion. Stability analysis of forced and torque-free spacecraft motion. Effects of space environment and man-made torques on motion stability. Examination of orbital and attitude motion coupling. Theoretical formulation of spacecraft formation flying. Review of current trends in networked miniaturized spacecraft. Overview and sizing of actuating devices such as gas jet, electric thrusters, momentum wheels and magnetic torquers. Overview and selection of sensing devices such as sun sensors, magnetometers, GPS, IMUs. Formulation of spacecraft maneuvers as control design problems. Case studies on feedback attitude regulators and algorithms for linear and nonlinear attitude tracking. Design and realization of attitude control schemes using Matlab®/Simulink®. (Prerequisites: Fundamentals of spacecraft orbital motion and attitude dynamics at the undergraduate level. Familiarity with state space and frequency domain control concepts such as stability, controllability and observability. Familiarity with Lyapunov-based stability analysis of nonlinear dynamical systems. Familiarity with Matlab®.)

AE 5224. Air Vehicle Dynamics and Control
(2 Credits)
This course covers the fundamentals of the dynamics of rigid bodies and their motion under the influence of aerodynamic and gravitational forces. General equations of aircraft motion will be developed, followed by concepts of static and dynamic stability. Trim and linearization will be discussed, and the stability analysis of lateral and longitudinal modes in the linearized equations will be introduced. Stability augmentation via feedback control will be discussed. Aspects of aircraft navigation, guidance, and flight trajectory optimization will also be introduced. (Prerequisites: Familiarity with the kinematics and dynamics of rigid bodies is required. Familiarity with ordinary differential equations is recommended. Familiarity with aircraft dynamics and control at the undergraduate level is beneficial, but not necessary.)

Materials and Structures

AE/ME 5380. Foundations of Elasticity
(2 credits)
This course is suitable as an introductory graduate level course. Topics will be chosen from the following: three-dimensional states of stress; measures of strain; thick-walled cylinders, disks and spheres; plane stress and plane strain; thermoelasticity; Airy stress function; energy methods, and exact theory for torsion of non-circular cross sections. This course may be taken independent of ME 5302.

AE/ME 5381. Applied Elasticity
(2 credits)
This course is suitable as an introductory graduate level course. Topics covered will be chosen from the following: bending and shear stresses in unsymmetric beams; bending of composite beams; bending of curved beams; torsion of thin-walled noncircular cross sections; beams on elastic foundations; stress concentrations; failure criteria; stability of columns; and bending of plates. This course may be taken independent of ME 5301.

AE 5382. Aeroelasticity
(2 credits)
Aeroelastic phenomena arise from the interaction between a fluid and a structure. Such phenomena are encountered in aerospace, mechanical and civil engineering systems. Topics covered include: aeroelastic phenomena in nature, divergence and control effectiveness in static conditions, static and dynamic instabilities of elastic bodies in a flow, flutter of wings, and aeroelastic testing techniques. Students will be introduced to analytical and computational techniques used to model and simulate aeroelasticity.

Return to Table of Contents

AE 5383. Composite Materials
(2 credits)
This course covers the anisotropic constitutive behavior and micromechanics of composite materials, and the mechanics of composite structures at an introductory graduate level. Topics covered will be chosen from: classification of composites (reinforcements and matrices), anisotropic elasticity, composite micromechanics, effect of reinforcement on toughness and strength of composites, laminate theory, statics and buckling of laminated beams and plates, statics of laminated shells, residual stresses and thermal effects in laminates.

Other Activities:

AE 5090. Graduate Aerospace Engineering Colloquium
(1/4 credit)
The Colloquium is a graduation requirement and offered once a week, during A, B, C, and D term. The Colloquium consists mainly of seminars presented by experts on technical and broader professional topics. Colloquium seminars are also presented by graduate students on topics related to their thesis, dissertation, independent research or industrial experiences. The Colloquium is offered in pass/fail mode and students registered for it are required to submit summary reports on the seminars presented. Recommended Background: graduate students in aerospace engineering.

AE 5093. Special Topics
(2 credits)
Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular aerospace engineering course offerings. Exact course descriptions are disseminated by the Aerospace Engineering Program in advance of the offering. (Prerequisite: Consent of instructor.)

AE 5098. Directed Research
(credits TBD)
These courses are offered by aerospace engineering faculty and cover diverse topics that range from 1 to 8 credits and may be completed in one or multiple terms. These courses provide M.S. and B.S./M.S. students the opportunity to gain research experience on topics of their interest. The required deliverables for successful completion of Directed Research are defined by the faculty offering the course and take into account the credits and topic involved. (Prerequisite: consent of faculty offering the Directed Research.)

AE 6093. Advanced Special Topics
(2 credits)
Arranged by individual faculty with special expertise, these courses cover advanced topics that are not covered by the regular aerospace engineering course offerings. Exact course descriptions are disseminated by the Aerospace Engineering Program in advance of the offering. (Prerequisite: Consent of instructor.)

AE 6098. Pre-Dissertation Research
(credits TBD)
For doctoral students wishing to obtain dissertation-research credit prior to admission to candidacy. (Prerequisite: Consent of dissertation advisor.)

AE 6099. Dissertation Research
(credits TBD)
For doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations. (Prerequisite: Consent of dissertation advisor.)

AE 6999. Ph.D. Qualifying Examination
(0 credits)
The written Qualifying Examination is intended to measure the fundamental ability of students admitted in the Ph.D. program in the three Core Areas of Study: fluids and propulsion; dynamics and control; materials and structures. The Qualifying Examination is given in the first week of D term and, if required, a retake of the Qualifying Examination is given in the middle of D Term. For students who enter the Ph.D. program in the fall, the Qualifying Examination must be taken after three terms. For students who enter the Ph.D. program in the spring, the Qualifying Examination must be taken after five terms.

The Qualifying Examination is graded using a Pass/Fail system with Pass/Fail grading in each of the three Core Areas of Study. A student may attempt the retake Qualifying Exam for the Core Areas of Study failed during the Qualifying Examination. A student must earn a Pass in all three Core Areas of Study in order to earn a Pass in the Qualifying Examination. Admission to candidacy is granted when a student has satisfactorily passed the AE 6999. Ph.D. Qualifying Examination.

Requirements: students must be enrolled in the Aerospace Engineering graduate program seeking a Ph.D. degree and must have the appropriate background in the three Core Areas of Study.

Return to Table of Contents

Bioinformatics and Computational Biology

Faculty with Research Interests

D. Korkin, Professor, Computer Science, and BCB Program Director; Ph.D., University of New Brunswick, Canada, 2003. Bioinformatics of disease, big data in biomedicine, computational genomics, systems biology, data mining, machine learning.

L. Harrison, Assistant Professor, Computer Science; Ph.D., UNC-Charlotte, 2013. Information visualization, visual analytics, human-computer interaction.

X. Kong, Associate Professor, Computer Science; Ph.D., University of Illinois, 2014. Data mining, social networks, machine learning, big data analytics, connectome.

A. Manning, Assistant Professor, Biology and Biotechnology; Ph.D., Geisel School of Medicine at Dartmouth University, 2008. Cancer Cell Biology, cell cycle regulation, mitotic progression and chromosome segregation, chromatin regulation, and genome stability.

S. D. Olson, Assistant Professor, Mathematical Sciences; Ph.D. North Carolina State University, 2008. Mathematical biology, chemical signaling, mechanics, and hydrodynamics.

R. Paffenroth, Associate Professor, Mathematical Sciences; Ph.D., University of Maryland, 1999. Large scale data analytics, statistical machine learning, compressed sensing, network analysis.

R. Prusty Rao, Professor, Biology and Biotechnology; Ph.D., Penn State University-Medical School. Genomic studies and high throughput screening to understand and manage fungal diseases in humans.

C. Ruiz, Professor, Computer Science; Ph.D., University of Maryland, 1996. Data mining, machine learning, artificial intelligence, biomedical data mining.

E. F. Ryder, Associate Professor, Biology and Biotechnology, and BCB Program Associate Director; Ph.D., Harvard University, 1993. Computational biology, simulation of biological systems.

B. Servatius, Professor, Mathematical Sciences; Ph.D., Syracuse University, 1987. Combinatorics, matroid and graph theory, structural topology, geometry, history and philosophy of mathematics.

S. Shell, Assistant Professor, Biology and Biotechnology; Ph.D., University of California San Diego. Bacterial pathogenesis, bacterial stress response, prokaryotic gene regulation, prokaryotic genomics and transcriptomics.

L. Vidali, Associate Professor, Biology and Biotechnology; Ph.D., University of Massachusetts-Amherst. Plant cell biology and molecular genetics, live cell microscopy, molecular motors/ cytoskeleton.

Z. Wu, Associate Professor of Mathematical Sciences, Ph.D., Yale, 2009. Biostatistics, high-dimensional model selection, linear and generalized linear modeling, statistical genetics, bioinformatics.

J. Zou, Associate Professor; Ph.D., University of Connecticut, 2009. Financial time series (especially high frequency financial data), spatial statistics, biosurveillance, high dimensional statistical inference, Bayesian statistics.

Affiliated Faculty

E.O. Agu, (Computer Science); Ph.D., University of Massachusetts-Amherst, 2001. Computer graphics, mobile computing, wireless networks, use of smartphones as a platform to deliver better healthcare.

A. Arnold (Mathematical Sciences); Ph.D., Case Western University, 2014. Mathematical biology, bayesian inference, parameter estimation in biological systems.

T. Dominko, (Biology and Biotechnology); D.V.M, Ph.D., University of Wisconsin-Madison. Regenerative cell biology, stem cells, role of oxygen and FGF2 in nuclear reprogramming, epigenetics, reproductive/developmental biology.

J. P. Duffy, (Biology and Biotechnology); Ph.D., University of Texas. Signal transduction dynamics and modeling, computational identification of intracellular protein motifs.

M. Eltabakh, (Computer Science); Ph.D., Purdue University, 2010. Database management systems, information management.

A. Mattson, (Chemistry and Biochemistry), Ph.D. Northwestern University: drug design, molecular modeling.

E. A. Rundensteiner, (Computer Science); Ph.D., University of California, Irvine, 1992. Data and information management, big data analytics, visual data discovery, stream and pattern mining, large scale data infrastructures.

J. Srinivasan, (Biology and Biotechnology); Ph.D., University of Tuebingen, Germany. Genetics, behavioral neuroscience, molecular neurobiology, chemical biology, evolutionary ecology.

D. Tang, (Mathematical Sciences); Ph.D., University of Wisconsin, 1988. Biofluids, biosolids, blood flow, mathematical modeling, numerical methods, scientific computing, nonlinear analysis, computational fluid dynamics.

S. Walcot, (Mathematical Science); Ph.D., Cornell University, 2006. Systems biology, molecular modeling, mathematical biology.

M. Wu, (Mathematical Sciences); Ph.D., University of California, Irvine, 2012. Mathematical biology, modeling of living systems.

A. Yousefi, (Computer Science). PhD., University of Southern California: computational neuroscience, neurostatistics.

Programs of Study

The Bioinformatics and Computational Biology (BCB) Program offers graduate studies toward the B.S./M.S., M.S., and Ph.D. degrees. With the advent of large amounts of biological data stemming from research efforts such as the Human Genome Project, there is a great need for professionals working at the interface

Return to Table of Contents

of biology, computer science, and mathematics. A truly interdisciplinary program, the BCB degree requires advanced course work in all three of these areas. Our faculty and strong relationships with the University of Massachusetts Medical School provide students with the resources to perform innovative scientific research at the highest level.

The diverse learning environment that characterizes our program promotes easy exchange of ideas, access to all the necessary resources, and encourages creative solutions to pressing scientific questions.

Admissions Requirements

Students applying to the M.S. or Ph.D. Degree Programs in Bioinformatics and Computational Biology (BCB) are expected to have a bachelor's degree in either biology, computer science, mathematics, or a related field, and to have taken introductory courses in each of the three disciplines: biology, computer science, and mathematics. For example, a student with a bachelor's degree in biology is expected to have also completed courses in programming, data structures, calculus, and statistics prior to submitting an application. A strong applicant who is missing background in one of the three areas may be provisionally admitted, with the expectation that he or she will take and pass one or more undergraduate courses in the area of deficiency either during the summer prior to admission or within the first semester after admission. The determination of what course or courses will satisfy this provision will be made by the Program Review Committee.

Certificate Requirements

A certificate program in BCB is not offered at present.

Degree Requirements

Masters: Students pursuing the M.S. degree in Bioinformatics and Computational Biology must complete a minimum of 33 credits of relevant work at the graduate level. These 33 credits must satisfy the 6-9 credit M.S. thesis or internship requirement, and the 24-27 credit coursework requirement described in detail at the URL below. Coursework requirements include competency in each of the areas of biology, computer science, mathematics, and interdisciplinary studies in bioinformatics / computational biology, as well as more advanced courses and an ethics course. The M.S. degree requirements have been designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively, students who are pursuing a combined B.S./M.S. degree, and students who are pursuing a combined M.S. / Ph.D. degree. Courses and research projects taken at nearby University of Massachusetts Medical School (UMMS) may be applied to this degree. Upon acceptance to the M.S. program, students will be assigned an academic advisor. In consultation with the academic advisor, the student must prepare a Plan of Study outlining the selections that the student will make to satisfy the M.S. degree requirements. This Plan of Study must then be approved by the Program Review Committee, which consists of faculty members from each of the three participating WPI departments.

B.S./M.S.: Students enrolled in the B.S./M.S. program must satisfy all the program requirements of the B.S. degree and all the program requirements of the M.S. degree as described at the URL below. They may double-count 4000-level or graduate courses whose credit hours total no more than 40% of the 33 credit hours required for the M.S. degree, and that meet all other requirements for each degree, towards both their undergraduate and graduate degrees. Students must register for B.S./M.S. credit prior to taking the courses, as faculty may assign extra work for those taking the course as part of both degrees. In consultation with the academic advisor, the student must prepare a Plan of Study outlining the selections that the student will make to satisfy the B.S./M.S. degree requirements, including the courses that the student will double count. This Plan of Study must then be approved by the Program Review Committee. Students must consult their advisors and the graduate catalog, as individual departments may have restrictions on which undergraduate courses might be taken for graduate credit, and on which pairs of undergraduate and graduate courses cannot both be taken for credit.

Ph.D.: Students pursuing the doctoral degree in BCB must complete a minimum of 90 graduate credits of relevant work beyond the bachelor's degree (60 credits if the student possesses a relevant M.S. degree). At least 30 credits must be in dissertation research. Coursework requirements are similar to those for the M.S. degree, with an additional required course in proposal writing. For Ph.D. candidates, presentation of research work is required each year, and there is a teaching / mentorship requirement as well. Students may pursue up to 6 graduate credits as an internship with an external sponsor. Detailed requirements are found at the URL below. Upon acceptance to the program, students will be assigned a temporary academic advisor and prepare a Plan of Study similar to the procedure for M.S. students. Ph.D. students are required to complete rotations with at least two program faculty members in the first year of the program before choosing a research advisor; choosing co-advisors in different disciplines is strongly encouraged. Students are encouraged to consider UMMS faculty for rotations and as co-advisors, and may take UMMS courses to fulfill course requirements.

Qualifying Exam and Dissertation Defense
The Qualifying Examination will be comprised of researching, writing, and defending a research proposal. The student is required to successfully complete the Qualifying Examination no later than the first semester of his/her third year in the program. If the Qualifying Examination is successfully completed, the proposed work may constitute the basis of the student's dissertation research. All Ph.D. students must produce and orally defend a dissertation. The research must constitute a contribution to knowledge in the field of Bioinformatics and Computational Biology and must be of publication quality. Students must defend the dissertation orally in a public presentation, followed by a private defense.

URL for details:
http://www.wpi.edu/+BCB

Facilities/Research Labs/ Research Centers

The BCB Program is supported by a wide assortment of resources within the participating departments, WPI Computing and Communication Center (CCC), and the research laboratories at Gateway Park and UMMS. Grid and cloud computing, along with high-speed networking, provides exceptional computational infrastructure. Access to most major biological databases is available to students and researchers, and a wide range of bioinformatics software packages are installed and maintained. Wet labs at Gateway Park and UMMS are available by permission of BCB faculty members and affiliates.

Course Descriptions

All courses are 3 credits unless otherwise noted.

BCB 501/BB 581. Bioinformatics

This course will provide an overview of bioinformatics, covering a broad selection of the most important techniques used to analyze biological sequence and expression data. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions. In addition, the course will provide students with an introduction to the theory behind some of the most important algorithms used to analyze sequence data (for example, alignment algorithms and the use of hidden Markov models). Topics covered will include protein and DNA sequence alignments, evolutionary analysis and phylogenetic trees, obtaining protein secondary structure from sequence, and analysis of gene expression including clustering methods. Students may not receive credit for both BCB 4001 and BCB 501. (Prerequisite: knowledge of genetics, molecular biology, and statistics at the undergraduate level.)

BCB 502/CS 582. Biovisualization

This course uses interactive visualization to explore and analyze data, structures, and processes. Topics include the fundamental principles, concepts, and techniques of visualization and how visualization can be used to analyze and communicate data in domains such as biology. Students will be expected to design and implement visualizations to experiment with different visual mappings and data types, and will complete a research oriented project. Prerequisite: experience with programming (especially JavaScript), databases, and data structures. Students may not receive credit for both BCB 502 and BCB 4002.

BCB 503/CS 583. Biological and Biomedical Database Mining

This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources, including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining. (Prerequisite: Strong programming skills, an undergraduate or graduate course in algorithms, an undergraduate course in statistics, and one or more undergraduate biology courses.)

BCB 504/MA 584. Statistical Methods in Genetics and Bioinformatics

This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees. Students may not receive credit for both BCB 4004 and BCB 504. (Prerequisite: knowledge of probability and statistics at the undergraduate level.)

BCB 510. BCB Seminar

(0 credits; pass/fail grading)

This seminar provides an opportunity for students in the BCB program to present their research work, as well as hear research talks from guest speakers.

BCB 590. Special Topics in Bioinformatics and Computational Biology

An offering of this course will cover a topic of current interest in detail. See the Supplement section of the online catalog at www.wpi.edu/+gradcat for descriptions of courses to be offered in this academic year. Prerequisites will vary with topic.

BCB 5900. Graduate Internship

A graduate internship is carried out in cooperation with a sponsor or industrial partner. It must be overseen by a faculty member affiliated with the Bioinformatics and Computational Biology Program. The internship will involve development and practice of technical and professional skills and knowledge relevant to Bioinformatics and Computational Biology. At the completion of the internship, the student will produce a written report, and will present their work to BCB faculty and internship sponsors.

BCB 596. Independent Study

This course will allow a student to study a chosen topic in Bioinformatics and Computational Biology under the guidance of a faculty member affiliated with the Bioinformatics and Computational Biology program. The student must produce a written report at the conclusion of the independent study.

BCB 597. Directed Research

Directed research conducted under the guidance of a faculty member affiliated with the BCB Program.

BCB 599. M.S. Thesis Research

A Master's thesis in Bioinformatics and Computational Biology consists of a research and development project worth a minimum of 9 graduate credit hours advised by a faculty member affiliated with the BCB Program. A thesis proposal must be approved by the BCB Program Review Board and the student's advisor before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document, and present the results to the BCB faculty in a public presentation.

BCB 699. Ph.D. Dissertation Research

A Ph.D. thesis in Bioinformatics and Computational Biology consists of a research and development project worth a minimum of 30 graduate credit hours advised by a faculty member affiliated with the BCB Program. Students must pass a qualifying exam before the student can register for Ph.D. thesis credits. The student must satisfactorily complete a written dissertation, and defend it in a public presentation and a private defense.

Return to Table of Contents

Biology and Biotechnology

Faculty

J. B. Duffy, Associate Professor and Department Head; Ph.D., University of Texas; defining signaling pathways that program cellular diversity.

T. Dominko, Professor; D.V.M., Ph.D., University of Wisconsin-Madison; investigation of the molecular basis of stem cell gene activation and induced pluripotency.

J. A. King, Professor and Peterson Family Dean of Arts and Sciences; Ph.D., New York University; M.S, City University of New York; neuronal plasticity associated with neurological and psychiatric disorders utilizing functional magnetic resonance imaging, molecular biology and behavior.

A. L. Manning, Assistant Professor; Ph.D., Dartmouth University-Geisel School of Medicine; cancel biology, cell cycle regulation, mitotic progression and chromosome segregation, chromatin regulation, and genome stability.

L. M. Mathews, Associate Professor; Ph.D., University of Louisiana; aquatic ecology, plant-insect coevolution, design and application of molecular genetic tools for ecological research, conservation biology.

I. Nechipurenko, Assistant Professor; Ph.D., Case Western Reserve University, School of Medicine; developmental neurobiology, genetics, cilia assembly and signaling in neurons.

K. K. Oates, Professor; Ph.D., The George Washington University Biochemistry; thymic hormone characterization, monoclonal antibody production, immunology of disease, undergraduate STEM education, STEM Education for Development.

R. P. Rao, Professor; Ph.D., Penn State University-Medical School; M.S (Dual), Drexel University; emerging Infectious diseases, virulence and host defense mechanisms.

J. Rulfs, Associate Professor; Ph.D., Tufts University; cell culture model systems of signal transduction, metabolic effects of phytoestrogens, cultured cells in tissue engineering.

E. F. Ryder, Associate Professor; Ph.D., Harvard University; M.S., Harvard School of Public Health; bioinformatics and computational approaches to understanding biological systems.

S. S. Shell, Assistant Professor; Ph.D., University of California San Diego; understanding how gene regulation controls stress responses and antibiotic sensitivity in mycobacteria.

J. Srinivasan, Associate Professor; Ph.D., University of Tuebingen, Germany; neural networks underlying social behaviors,role of olfactory dysfunction in neurodegenerative disorders, optogenetics & engineering of neural networks.

L. Vidali, Associate Professor; Ph.D., University of Massachusetts-Amherst; understanding the molecular and cellular mechanisms underlying the role of the cytoskeleton in plant cell organization and growth.

P. J. Weathers, Professor; Ph.D., Michigan State University; investigation of *Artemisia annua* antimalarial, antimicrobial drug production in *planta*, and bioavailability and therapeutic efficacy *in vitro* and *in vivo.*

Research Interests

Enabled by a world-class research infrastructure, students explore their passion for discovery while driving cutting-edge, hypothesis-driven research alongside our diverse and dynamic faculty body. Faculty areas of expertise in which students may engage in directed student include:

- Cancer cell biology
- Cognition and behavior
- Cytoskeletal dynamics
- Drug resistance
- Epigenetics and gene regulation
- Infectious diseases
- Neurobiology
- Regenerative medicine
- Signal transduction mechanisms

The department strongly recommends that, prior to applying, prospective students review the information on the department's website to identify potential research interests and faculty advisors.

Molecular and Cellular Biology and Biotechnology

Areas of focus: Cytoskeletal dynamics, epigenetics/gene regulation, and signal transduction mechanisms

Biological systems: *C. elegans, Drosophila, M. musculus, Physcomitrella*, and *C. albicans*, *S. cerevisae,* Cultured cells

Faculty: Tanja Dominko, Joe Duffy, Amity Manning, Lauren Mathews, Inna Nechipurenko, Reeta Rao, Jill Rulfs, Liz Ryder, Scarlet Shell, Jagan Srinivasan and Luis Vidali.

Development, Neurobiology, and Organismal Biology and Biotechnology

Areas of focus: Cancer biology, regenerative medicine, neuronal migration, circuits, and degeneration, pathogenic mechanisms, and plant biology

Model systems: *C. elegans, Drosophila, M. musculus, Physcomitrella,* and *C. albicans,* Cultured cells

Faculty: Tanja Dominko, Joe Duffy, Amity Manning, Inna Nechipurenko, Reeta Rao, Liz Ryder, Scarlet Shell, Jagan Srinivasan, and Luis Vidali.

Behavioral and Environmental Biology and Biotechnology

Areas of focus: Animal behavior, biological diversity, brain plasticity, pollinator ecology, and plant biology

Model systems: *Danaus plexippus, Orconectes spp.*, and *Drosophila*

Faculty: Joe Duffy, Lauren Mathews, Jagan Srinivasan and Pam Weathers.

Programs of Study

With the advent of genomics, the 21st Century has been termed a "revolutionary" era in Biology and Biotechnology. The Department of Biology and Biotechnology (BB) is perfectly situated for this transition with the construction of the Interdisciplinary Life Sciences and Bioengineering Center at Gateway Park. This state-of-the-art building integrates Life Sciences

Return to Table of Contents

and Bioengineering at WPI in addition to housing a number of technology centers and biotechnology start-ups.

The Department offers a fulltime research-oriented program for incoming graduate students, leading to either a doctor of philosophy (Ph.D.) in Biology and Biotechnology or Masters (M.S.) degree in Biology and Biotechnology. These programs require students to successfully complete a set of required courses in the field and a thesis project or dissertation that applies the basic principles of biology and biotechnology using hypothesis driven experimental methods to address a specific research problem.

In addition, the department also offers a skills-based non-thesis MS degree in Biotechnology, delivered in a blended format. The non-thesis M.S. program is designed to provide a broad base in advanced coursework and laboratory training in techniques that are applicable to the Biotechnology industry.

Graduates will have a broad knowledge of the field of biology and biotechnology, a detailed knowledge in their area of specialization, a working knowledge of modern research tools, a strong appreciation for scientific research in theoretical and experimental areas, and a foundation for lifelong learning and experimenting, both individually and as part of a team. Students who complete these programs will be well prepared for careers in the academics and private sectors or further graduate education.

Application and Admission

Applications should be made to the specific degree programs. The department accepts applications for admission to the M.S. or Ph.D. in biology and biotechnology programs in the Fall semester only. M.S. in Biotechnology applications are reviewed on a rolling basis.

Admission Requirements

See page 9.

Degree Requirements

Ph.D. in Biology and Biotechnology

In addition to the WPI requirements, a dissertation (minimum of 30 credit hours) and dissertation defense is required of all Ph.D. students. It is the intention of the faculty that doctoral students develop skills not only in their research area, but also receive training in interdisciplinary approaches to research, presentation skills (oral and written), pedagogical approaches, experimental design, and professional ethics within the life sciences. Specific operational details of the program, including the qualifying exam and dissertation defense, can be found in the Biology and Biotechnology graduate handbook.

Publications

All successful Ph.D. students are expected to have at least one author-manuscript published or accepted for publication in a peer-reviewed journal. In addition, the students are required to present their thesis work at a national or international conference.

Qualifying Exam, Reports and Dissertation Defense

A Ph.D. qualifying exam is required and should be taken towards the end of the second year of study. A majority of the Examining Committee must be members of the Biology and Biotechnology department faculty. The committee must also approve the student's dissertation research proposal and review student's progress through committee meetings. Candidates for the Ph.D. degree must give annual presentations of their research work to the department as part of the graduate seminar course. A public defense of the completed dissertation is required of all students and will be followed immediately by a defense before the Examining Committee. All members of the Examining Committee must be present for the defense.

M.S. in Biology and Biotechnology (thesis-based)

Students pursuing the M.S. degree in Biology and Biotechnology must successfully complete a minimum of 30 credit hours of course and thesis work per the distribution requirement below. All courses must be at the 500 or 4000 level and no more than 9 credits may be at the 4000 level. An approved list is provided in the department's graduate handbook.

Credit Requirement:

Course work at the 500 or 4000 level	15 CR
Thesis Research	15 CR (recommended)

Course Requirement:

BB 554 Journal Club	1 CR
BB 551 Research Integrity in the Sciences	1 CR
BB 501 Seminar	1 CR (minimum of 4)
BB course(s)	3 CR
Electives (approved by Advisory Committee)	6 CR
BB 599 Thesis Research	15 CR (recommended)

Students must assemble an Advisory Committee of three or more faculty members of which a majority must be Biology and Biotechnology program faculty members. The Advisory Committee must review and approve each M.S. student's program of study and thesis research. Students must successfully complete a thesis including a written thesis and oral defense.

M.S. in Biotechnology (skills-based):

Students pursuing skills-based M.S. degree in Biotechnology must complete a minimum of 30 credit hours beyond the bachelor's degree. Students enrolled in the M.S. in Biotechnology program must successfully complete 15 credit hours of BB courses, 9 credit hours of skills-based courses, chosen from an approved list provided below and 6 credit hours of elective courses. All courses must be at the 500 or 4000 level and no more than 9 credits may be at the 4000 level. An approved list is provided below. Additional courses will require approval of graduate co-ordinator.

Credit Requirement:

BB courses (at the 500 or 4000 level)	15 CR
Electives (approved by advisory committee)	6 CR
Skills-based courses (**)	9 CR

Approved list of courses for Skills-based M.S. degree in Biotechnology

Courses

BB 501 Seminar
BB 570 Special Topics
BB 551 Research Integrity in the Sciences
BB 552 Scientific Writing and Proposal Development
** BB 553 Experimental Design and Statistics in the Life Sciences
BB 554 Journal
BB 556 Mentored Teaching Experience
BB 515 Environmental Change: Problems and Approaches
** BB 505 Fermentation Biology
** BB 5xx Animal Cell Culture
** BB 509 Scale Up of Bioprocessing
** BB 560 Methods of Protein Purification and Downstream Processing
BB 565 Virology
BB 561 Model Systems: Experimental Approaches and Applications
BB 562 Cell Cycle Regulation
BB 575 Advanced Genetics and Cellular Biology
** BB 581 Bioinformatics
** BB 598 Directed Research
** BB 4xxx Capstone courses

Related Courses

** BCB 502 Biovisualization
CH 540 Regulation of Gene Expression
CH 555 Advanced Topics
CH 560 Current Topics in Biochemistry
** CH 561 Functional Genomics
CH 4110 Biochemistry I
CH 4120 Biochemistry II
CH 4130 Biochemistry III
** CH 516 Chemical Spectroscopy
** CH 536 NMR Spectroscopy
CH 538 Medicinal Chemistry
CH 541 Membrane Biophysics
** CH 554 Molecular Modeling
CHE 521 Biochemical Engineering
** BME 562 Small animal surgery
** BME 550 Tissue Engineering
MIS 576 Project Management
FIN 500 Financial information in Management

Certificate in Biomanufacturing

The Graduate Certificate in Biomanufacturing must be composed of 12 credits of graduate coursework chosen from a list provided in the graduate catalog and approved by the BBT graduate coordinator:

- **Three skills-based courses (9 credits).** Courses include: BB505 Fermentation Biology, BB508 Animal Cell culture, BB509 Scaleup of Bioprocessing, BB560 Methods of Protein Purification and Downstream processing, BB581 Bioinformatics
- **One, thematically related, graduate level course (3 credits)** Courses include: BB 551 Research Integrity in the Sciences, BB 590, Integrative in Biology and Biotechnology, BB 561 Model Systems: Experimental Approaches and Applications, BB 562 Cell Cycle Regulation, BCB 502 Biovisualization, CH 540 Regulation of Gene Expression, CHE 521 Biochemical Engineering

Research Facilities and Centers

Life Sciences and Bioengineering Center (LSBC)

Located in Gateway Park, the world-class, 124,600-square-foot LSBC was built in 2007 and serves as the school's focal point for graduate education and research in the life sciences and related bioengineering fields. It's also home to life sciences companies, state-of-the-art core facilities, and WPI's Corporate and Professional Education division.

The Core facilities include an Imaging core providing a wide range of imaging capabilities for live and fixed samples including Confocal microscopy with FRET and FRAP, Atomic Force Microscopy, and microinjection/manipulation and histology capabilities; an Analytical core, with NMR, Atomic-absorption (AA) spectroscopy, LC-MS and GC-MS capabilities; and Molecular Cores for DNA/RNA/tissue work. Additional shared common spaces include centralized facilities for waste disposal, media preparation as well as dishwashing. The facility is part of the WPI-University of Massachusetts Consortium which allows researchers at both institutions to access facilities and services at the other institution at "in-house" rates.

Bioprocess Center (BPC)

Researchers at the BPC design and develop scalable processes for drug manufacturing. The BPC contracts with biotechnology companies, to supply drug targets in research quantities and conduct lab- and pilot-scale process development.

Biomanufacturing Education and Training Center (BETC)

WPI's Biomanufacturing Education and Training Center, the first of its kind in the Northeast, provides innovative workforce development solutions customized to the specific needs of an industry. Serving life sciences companies from across the region and the globe, the center represents an innovative partnership of academia and industry by offering hands-on and classroom training by experts in a wide-range of roles and disciplines.

Course Descriptions

BB 501. Seminar
(1 credit; pass/fail grading)

BB 504. Molecular Biology of the Cell

This course will facilitate a student's functional knowledge of living cells from a biological, biochemical and technological perspective. Topics covered will include the structure, organization, growth, regulation, movements, and interaction of cells, as well as details of cellular metabolism and molecular biology. Emphasis will be placed on visualizing cellular architecture, describing the structure of DNA, describing the fate of various cellular RNAs, articulating information flow in cells, and describing protein outcomes. This course is intended to achieve a homogenous level of student understanding and can be used as a foundation course for the program.

This course is designed to familiarize students with basic concepts of molecular biology including structure, organization, growth, regulation, movements, and interactions within a cell. Details of metabolism and molecular biology will be covered through projects and study of the primary literature to achieve a homogenous level of student understanding and rigor. Weekly online assessments are designed to ensure understanding.

Note: Students may not receive credit for BB 504 and BB 570-196.

BB 505. Fermentation Biology

(3 credits)

Material in this course focuses on biological (especially microbiological) systems by which materials and energy can be interconverted (e.g., waste products into useful chemicals or fuels). The processes are dealt with at the physiological and the system level, with emphasis on the means by which useful conversions can be harnessed in a biologically intelligent way. The laboratory focuses on measurements of microbial physiology and on bench-scale process design.

BB 508. Animal Cell Culture

Animal cell culture technology is about maintaining cells in vitro under controlled conditions. In recent decades this technology has advanced significantly, and animal cells are used in variety of application both in research and product development. The students in this course will be exposed to the different methodologies utilized to grow cells and how this technology is becoming critical in production of many of the health care products used to control human diseases.

The course is covers four general skills (1) Basic techniques for culturing and sub-culturing animal cells and growth parameters, (2) Quality control of a cell culture laboratory/How to control contamination, (3) Primary cell culture and development of cell lines, and (4) Scale-up of cell culture from a T-Flask to a bioreactor.

Note: Students may not receive credit for BB 508 and BB 570-198

BB 509. Scale Up of Bioprocessing

(3 credits)

Strategies for optimization of bioprocesses for scale-up applications will be explored. In addition to the theory of scaling up unit operations in bioprocessing, students will scale up a bench-scale bioprocess (5 liters), including fermenta- tion and downstream processing to 55 liters. Specific topics include the effects of scaling up on: mass transfer and bioreactor design, harvesting techniques including tangential flow filtration and centrifugation, and chromatography (open column and HPLC).

BB 515. Environmental Change: Problems and Approaches

(3 credits)

This seminar course will examine what is known about ecological responses to both natural and human-mediated environmental changes, and explore approaches for solving ecological problems and increasing environmental sustainability. Areas of focus may include, and are not limited to, conservation genetics, ecological responses to global climate change, sustainable use of living natural resources, and the environmental impacts of agricultural biotechnology.

BB 551. Research Integrity in the Sciences

(1 credit)

Students are exposed to various issues related to integrity in doing research to enable development of an appropriately reasonable course of action in order to maintain integrity on a variety of research-related performance and reporting activities. These activities include, but are not limited to data fabrication, authorship, copyright, plagiarism, unintended dual use of technology, and responsibilities towards peers who may request your confidential review or feedback. The course will use class discussion, case studies, and exercises to facilitate an understanding of the responsibilities of scientists to their profession. Students may receive credit for either BB551 or a BB570 course entitled Research Integrity in the Sciences but not both.

BB 552. Scientific Writing and Proposal Development

(3 credits)

This course will cover key elements to writing successful grant proposals and manuscripts. This includes project development, identification of funding agencies or journals, proposal and manuscript writing and editing, as well as aspects of the submission and review process. Students will be expected to develop a NIH/NSF style postdoctoral proposal outside their dissertation field and participate in a mock proposal review panel. Students are expected to complete this course prior to their Qualifying Exam. Students may receive credit for either BB552 or a BB570 course entitled Scientific Writing and Proposal Development but not both.

BB 553. Experimental Design and Statistics in the Life Sciences

(3 credits)

This applied course introduces students to the basics of experimental design and data analysis. Emphasis will be placed on designing biological experiments that are suitable for statistical analysis, choosing appropriate statistical tests to perform, and interpreting the results of statistical tests. We will cover statistical methods commonly used by biologists to analyze experimental data, including testing the fit of data to theoretical distributions, comparisons of groups, and regression analysis. Both parametric and non-parametric tests will be discussed. Students will use computer packages to analyze their own experimental data. Students may receive credit for either BB553 or a BB570 course entitled Experimental Design and Statistics in the Life Sciences but not both.

BB 554. Journal Club

(1 credit)

This course is offered every semester covering different topics, both basic and applied, in Biology and Biotechnology and rotates among the faculty. Students read and discuss the literature in relevant topics.

BB 556. Mentored Teaching Experience

(1 credit)

This course is arranged with an individual faculty member within the student's discipline. The graduate student is involved in the development of course materials, such as a syllabus, projects, or quizzes, and course delivery, such as lecturing or facilitating a conference session (20% delivery limit). In addition to covering course pedagogy, the faculty member arranges for the student teacher to be evaluated by students enrolled in the course and reviews the student reports with the student teacher.

BB 560. Methods of Protein Purification and Downstream Processing

(3 credits)

This course provides a detailed hands-on survey of state-of-the-art methods employed by the biotechnology industry for the purification of products, proteins in particular, from fermentation processes. Focus is on methods that offer the best potential for scale-up. Included is the theory of the design, as well as the operation of these methods both at the laboratory scale and scaled up. It is intended for biology, biotechnology, chemical engineering and biochemistry students. (Prerequisite: knowledge of basic biochemistry is assumed.)

BB 561. Model Systems: Experimental Approaches and Applications

(2 credit)

The course is intended to introduce students to the use of model experimental systems in modern biological research. The course covers prokaryotic and eukaryotic systems including microbial (*Escherichia coli*) and single cells eukaryotes (fungi); invertebrate (*Caenorhabditis elegans, Drosophila melanogaster*) and vertebrate (mice, zebra fish) systems and plants (moss, algae and *Arabidopsis thaliana*). Use of these systems in basic and applied research will be examined. Students may receive credit for either BB561 or a BB570 course entitled Model Systems: Experimental Approaches and Applications but not both.

BB 562. Cell Cycle Regulation

(3 credits)

This course focuses on molecular events that regulate cell cycle transitions and their relevance to mammalian differentiated and undifferentiated cells. Topics include control of the G1/S and G2/M transitions, relationships between tumor suppressor genes such as p16, Rb, p53 or oncogenes such as cyclin D, cdc25A, MDM2 or c-myc and cell cycle control. Where appropriate, the focus is on understanding regulation of cell cycle control through transcriptional induction of gene expression, protein associations, posttranslational modifications like phosphorylation or regulation of protein stability like ubiquitin degradation. Students may receive credit for either BB562 or a BB570 course entitled Cell Cycle Regulation but not both.

Return to Table of Contents

BB 565. Virology
(3 credits)

This advanced level course uses a seminar format based on research articles to discuss current topics related to the molecular/cell biology of viral structure, function, and evolution. Particular emphasis is placed on pathological mechanisms of various human disorders, especially emerging disease, and the use of viruses in research.

BB 570. Special Topics
(variable credit)

Specialty subject courses are offered based on the expertise of the department faculty such as Stem Cell Biology.

BB 575. Advanced Genetics and Cellular Biology
(3 credits)

Topics in this course focus on the basic building blocks of life: molecules, genes and cells. The course will address areas of the organization, structure, function and analysis of the genome and of cells. (Prerequisite: A familiarity with fundamentals of recombinant DNA and molecular biological techniques as well as cell biology.)

BB 581/BCB 501. Bioinformatics
(3 credits)

This course will provide an overview of bioinformatics, covering a broad selection of the most important techniques used to analyze biological sequence and expression data. Students will acquire a working knowledge of bioinformatics applications through hands-on use of software to ask and answer biological questions. In addition, the course will provide students with an introduction to the theory behind some of the most important algorithms used to analyze sequence data (for example, alignment algorithms and the use of hidden Markov models). Topics covered will include protein and DNA sequence alignments, evolutionary analysis and phylogenetic trees, obtaining protein secondary structure from sequence, and analysis of gene expression including clustering methods. (Prerequisite: knowledge of genetics, molecular biology, and statistics at the undergraduate level.) Students may not receive credit for both BB 581 and BB 4801.

BB 590. Capstone Experience in Biology and Biotechnology

These classes will serve as integrative experiences for graduate students who are early in their doctoral training. The course will help students integrate concepts from other courses in the curriculum, practice skills of critical analysis, and evaluate and communicate scientific information effectively. The specific theme of each offering will center around a current topic of biological interest, and may include such areas as genomics, cancer, environmental problems, and synthetic biology. Topics will be announced prior to registration in the year preceding the course offering.

NOTE: Students may not earn credit for both BB 4900 and BB 590 that bear the same section number and course description.

BB 598. Directed Research

Directed research conducted under the guidance of a faculty member in the BB Program.

BB 599. Master's Thesis

A Master's thesis in Biology and Biotechnology consists of a research and development project worth a minimum of 9 graduate credit hours advised by a faculty member in the BB Program. The student must satisfactorily complete a written dissertation, public presentation, and private defense with thesis committee.

BB 699. Ph.D. Dissertation

A Ph.D. thesis in Biology and Biotechnology consists of a research and development project worth a minimum of 30 graduate credit hours advised by a faculty member affiliated with the BB Program. Students must pass a qualifying exam before the student can register for Ph.D. thesis credits. The student must satisfactorily complete a written dissertation, defend in a public presentation and private defense with thesis committee.

Biomedical Engineering

www.wpi.edu/+bme

Faculty

K. L. Billiar, Professor and Department Head; Ph.D., University of Pennsylvania; Biomechanics of soft tissues and biomaterials, mechanobiology, wound healing, tissue growth and development; functional tissue engineering, regenerative medicine.

D. R. Albrecht, Associate Professor; Ph.D., University of California, San Diego; bioMEMS, microfluidics, quantitative systems analysis and modeling, biodynamics, neural circuits and behavior, optogenetics, high-throughput chemical/genetic screens, tissue engineering, 3-D cell micropatterning, dielectrophoresis.

J. Coburn, Assistant Professor; Ph.D., Johns Hopkins University; biomaterials, scaffolds, tissue engineering, 3-D tissue models, stem cells, cell-matrix/material interactions, drug delivery, oncology therapeutics.

G. R. Gaudette, William Smith Dean's Professor of BME; Ph.D., SUNY Stony Brook; Cardiac biomechanics, myocardial regeneration, biomaterial scaffolds, tissue engineering, stem cell applications, optical imaging techniques, cellular agriculture, crossing biological kingdoms.

S. Ji, Associate Professor; D.Sc., Washington University in St. Louis; Biomechanics, brain injury, finite element analysis, multi-scale modeling, neuroimaging, medical image analysis, sports medicine.

A.C. Lammert, Assistant Professor; Ph.D., University of Southern California; Neuroengineering, computational modeling, signal processing, sensorimotor control, brain health.

G. D. Pins, Professor; Ph.D., Rutgers University; Cell and tissue engineering, biomaterials, bioMEMS, scaffolds for soft tissue repair, cell-material interactions, wound healing, cell culture technologies.

M. W. Rolle, Associate Professor, Ph.D., University of Washington, Seattle; Cardio-vascular tissue engineering, bioreactor design, cell-based tissue repair, cell and molecular engineering, cell-derived extracellular matrix scaffolds, delivery and control of extracellular matrix genes.

K. L. Troy, Associate Professor; Ph.D., University of Iowa; orthopedic biomechanics, multi-scale modeling, finite element analysis, medical image analysis, bone and joint structure.

C. F. Whittington, Assistant Professor; Ph.D., Purdue University; Cell-extracellular matrix interactions, biomaterials, 3D culture, tissue engineering, mechanobiology, disease models, tumor microenvironment, tumor metastasis, phenotypic assay development, high-throughput and high-content screening.

H. Zhang, Assistant Professor; Ph.D., Johns Hopkins University; Biomedical robotics, biomedical imaging, ultrasound and photoacoustic instrumentation, functional imaging of brain and cancer, image-guided therapy and intervention.

Research Interests

Biomedical engineering (BME) faculty and graduate students work in multi-disciplinary teams across campus, as well as with external collaborators in academia, medicine and industry. Biomedical engineering graduate students may conduct thesis and dissertation research and projects under the supervision of primary BME department faculty or collaborative BME faculty advisors. Please refer to the Biomedical Engineering Department website for a current listing of primary and collaborative faculty (www.wpi.edu/+bme) and their research interests. Primary areas of research focus include:

Biomaterials and Tissue Engineering

Several BME researchers at WPI focus on creating biomaterials and engineered tissues for regenerative medicine and drug discovery applications. Research projects include: engineered biomaterials for cell delivery and tissue repair (cardiac patches and skeletal muscle regeneration), microtissue models of normal and diseased human tissues (liver, cardiovascular, skeletal muscle and cancer), advanced biomanufacturing of cells, biomolecules, biomaterials, and tissue biofabrication. More recent interdisciplinary work focuses on the use of decellularized plant tissues as biomaterials, and exploring the plant-animal cell interface for the development of advanced biomanufacturing and tissue engineering processes.

Primary faculty: Billiar, Coburn, Gaudette, Pins, Rolle, Whittington
Collaborative faculty: Camesano, Dominko, Roberts, Soboyejo, Weathers

Biomechanics and Mechanobiology

Biomechanics research at WPI focuses on measuring the effects of mechanical forces on skeletal and soft tissue remodeling, and using imaging data and computational tools to understand these effects in the context of human organ and tissue function. Projects include quantifying the effects of exercise and pathology (aging, injury and non-loading, such as in spinal cord injury) on bone remodeling and mechanics, modeling concussion injury in the brain, and applications of robotics in rehabilitative medicine and image-guided surgery. Mechanobiology research aims to understand the mechanical forces through which cells act on and respond to their environment within normal and diseased tissues (heart valve disease, cardiac repair, cancer).

Primary faculty: Billiar, Gaudette, Ji, Troy, Zhang
Collaborative faculty: Fischer, Fofana, Popovic, Tang, Wen

Bioinstrumentation and Signal Processing

Bioinstrumentation research at WPI focuses on developing sensors for physiological monitoring (pulse oximeters, pressure ulcer sensors). Signal processing research extends to the application of quantitative microscopy and machine learning to identify cell phenotypes associated with health and disease (cancer metastasis, quality assessment for cell manufacturing). Quantitative microscopy and imaging, combined with microfabricated MEMS devices for whole organism studies (*C. elegans*), are being

Return to Table of Contents

applied to enable high throughput and bioinformatics analysis of neurobiology networks and behavior to model human neurobiology (sleep, autism).

Primary faculty: Albrecht, Lammert, Mendelson
Collaborative faculty: Clancy, Liu

Research Laboratories and Facilities

Biomedical Engineering research laboratories are located in the four-story, 125,000-square-foot **WPI Life Science and Bioengineering Center (LSBC)** at Gateway Park (60 Prescott Street). Laboratory capabilities and equipment include:

Biomaterials fabrication (electrospinning, polymer synthesis, chemical modification, plant- and animal-based biomaterial processing and synthesis)

Biomedical sensors and bioinstrumentation (design and microfabrication of reflective pulse oximetry sensors, microcomputer-based biomedical instrumentation, digital signal processing, wearable wireless biomedical sensors, application of optics to biomedicine and telemedicine)

Cell culture (class I and II biosafety cabinets, incubators, supporting infrastructure)

Histology (paraffin processing and embedding equipment, microtomes, cryotome and special staining stations)

Medical imaging (quantitative computed tomography to measure mineralization in bone)

Microfabrication lab (rapid prototyping microfluidic and microelectical mechanical systems (MEMS))

Microscopy (multiple inverted and epifluorescent microscopes, confocal microscopes, atomic force microscopes, light sheet imaging, live still and video image capture of cells, tissues and organisms, fluorescent tracking and quantitative analysis of neural and muscle cell activity)

Mechanical testing (Instron EPS 1000; custom mechanical testing and conditioning systems)

Motion capture and computational mechanics (head impact sensors, gait analysis, high density mapping of soft tissue mechanics, integration of medical imaging data with multi-scale and finite element modeling of musculoskeletal and brain injury biomechanics)

In addition, biomedical engineering faculty and students have access to other WPI facilities and resources at Gateway Park, including courses and equipment housed in the **Biomanufacturing Education and Training Center** (BETC), and courses and events at the **Foisie School of Business**, both located next door to LSBC at 50 Prescott Street. **Robotics Program** research laboratories are located across the street at 85 Prescott Street.

Two new WPI Gateway Park research facilities opened in 2019: **Practice Point** is a new facility that houses point-of-care suites where industry-clinician-academic research teams will collaborate to develop advanced healthcare technologies. Research focus areas include medical and surgical robotics, image-guided robotic surgery, assistive technologies, home health care, digital and connected health systems, and advanced prosthetic and rehabilitative engineering.

Advanced Integrated Manufacturing (AIM) Photonics Lab (in partnership with Quinsigamond Community College) enables rapid prototyping, testing, and training in advanced sensing technology to support economic and workforce development and innovation in manufacturing.

AIM is one of the eight national **Manufacturing USA Institutes** of which WPI is a member. This has enabled unique opportunities to engage in industry-government-academic research partnerships that create value for areas of national need in advanced manufacturing. Primary and collaborative BME faculty are active members of the **Advanced Regenerative Medicine Institute (ARMI) and National Institute for Innovation in Manufacturing**.

Boston Seaport

In January 2018, WPI opened the doors to a new space at the heart of Boston's Seaport District, home to a number of innovative technology companies. The facility houses a classroom, conference room, event space, and several meeting spaces that can be reserved by student and faculty teams working with Boston and Cambridge companies, academic or clinical research partners.

Regional Research Partnerships

WPI's geographic location in the heart of central Massachusetts makes it accessible to regional academic and medical centers in Boston and Cambridge, and hundreds of medical device and biotechnology companies, hospitals and research facilities throughout the northeast.

University of Massachusetts Medical School (UMMS) is located in Worcester less than 2 miles from the WPI campus. BME faculty and students engage in many active collaborations with faculty and clinicians at UMMS. With guidance and approval from the BME Graduate Studies Committee, BME graduate students may take courses and pursue research and projects advised by BME program faculty at UMMS.

U.S. Army Natick Soldier Research, Development and Engineering Center (NSRDEC) is located in nearby Natick, Massachusetts. BME faculty and students engage in collaborative projects focused on making soldiers' lives easier, healthier, and safer.

Tufts Cummings School of Veterinary Medicine is located in nearby Grafton, Massachusetts (approximately 8 miles from WPI campus). BME faculty and students engage in research and design projects in collaboration with veterinarians and research faculty at Tufts to improve veterinary medicine.

Programs of Study

The goal of the biomedical engineering (BME) graduate programs is to apply engineering principles and technology that create value and innovative approaches to solve significant biomedical problems. Students trained in these programs have found rewarding careers in major medical and biomedical research centers, academia, medical device and biotechnology industries, and entrepreneurial enterprises.

BME graduate programs are designed to be flexible, student-centered, and customizable to each individual student's academic background, professional experience, and career goals. Courses may be taken on campus or online (as available). Depending on the specific degree program, coursework, thesis and dissertation research, and project work may be integrated with industry co-ops and internships, full-time employment in a related industry, or an international research experience.

Each admitted and matriculated student is assigned a BME Faculty Academic Advisor to provide guidance on course selection and degree program planning. In addition, all students submit an individual Plan of Study to the BME Graduate Studies Committee for review during their first semester, and periodically throughout their degree program, for feedback to ensure that they are on track to meet degree requirements.

All BME graduate degree programs adhere to WPI's general requirements detailed in the WPI Graduate Catalog.

Doctoral Programs

The degree of doctor of philosophy in Biomedical Engineering is conferred on candidates in recognition of exceptional academic achievement and the ability to carry on original independent research. Graduates of the program will be prepared to lead research projects in academic institutions, government agencies, or in the medical device and biotechnology industries.

Master's Degree Programs

There are two master's degree options in biomedical engineering: the course-based Master of Engineering (M.E.), and the Master of Science (M.S.) in Biomedical Engineering. For the M.S. degree, students may choose a Thesis-Based or Project-Based program of study. While the expected levels of student academic performance are the same for all three degree options, they are oriented toward different career goals. The Thesis-Based M.S. is oriented toward the student who wants to focus on a particular facet of biomedical engineering practice or research, or as preparation for pursuing doctoral research. Due to the nature of open-ended independent research, a thesis project may extend beyond the time required to complete the required courses in the Project-Based M.S. or M.E. degree programs. The Project-Based M.S. option is designed to gain hands-on technical experience by engaging in defined engineering design projects relevant to clinical or industry stakeholders. The M.E. option is course-based and designed for the student interested in acquiring advanced technical depth in an area of biomedical engineering specialization, and may be completed on campus or online. The M.S. or M.E. degrees can serve as a terminal degree for students interested in advanced technical training, professional development, and specialization in biomedical engineering.

Combined B.S./Master's Degree Program

This program affords an opportunity for outstanding WPI undergraduate students to earn both a B.S. degree and a master's degree in biomedical engineering concurrently, and in less time than would typically be required to earn each degree separately. The principal advantage of this program is that it allows for certain credits to be counted towards both degree requirements, thereby reducing the total number of courses taken to earn both degrees. With careful planning and motivation, the Combined Program typically allows a student to complete requirements for both degrees with only one additional year of full-time study beyond the B.S. degree (five years total). However, because a student must still satisfy all degree requirements, the actual time spent in the program may be longer than five years.

Students in the Combined Program may choose to complete any one of the master's degree options: a Thesis-Based or Project-Based Master of Science (B.S./M.S.) or a Master of Engineering (B.S./M.E.).

Admissions Requirements

Biomedical engineering embraces the application of engineering to the study of medicine and biology. While the scope of biomedical engineering is broad, applicants are expected to have an undergraduate degree or a strong background in engineering and to achieve basic and advanced knowledge in engineering, life sciences, and biomedical engineering. Applicants with degrees in physical and computational sciences, including physics, computer science and applied mathematics are also encouraged to apply.

Applicants with undergraduate degrees in biology or pharmacy that do not have a strong computational or engineering focus are encouraged to explore advanced degree programs offered by collaborating WPI Life Science and Bioengineering departments, such as Biology and Biotechnology (BBT), Bioinformatics and Computational Biology (BCB) or Chemistry and Biochemistry (CBC).

Degree Requirements

For the M.S.

A minimum of 30 credit hours is required for the Master of Science degree, which may be met by satisfying the requirements for a Thesis-Based or Project-Based program of study. BME courses include BME 500-level or 4000-level courses (except BME 4300. MQP Capstone Design). Electives may include any WPI graduate-level engineering, physics, math, biomedical engineering, or equivalent course (500- or 4000-level), subject to the approval of the department Graduate Studies Committee. A maximum of 8 credits of coursework at the 4000-level may be applied to meet the requirements for the Master of Science degree.

M.S. (Thesis-Based) 30 credits
BME courses 12 credits
BME 599 (M.S. Thesis) 6 credits minimum
Electives 12 credits

M.S. (Project-Based) 30 credits
BME courses 12 credits
BME 597 (M.S. Project) 6 credits
Electives 12 credits

BME courses: BME courses are defined as any course with a BME designator.

Thesis (6 credits, Thesis-Based M.S.)

The Thesis-Based M.S. program requires a minimum of 6 credits of **BME 599. Master's Thesis** and completion of an independent research project under the supervision of a Biomedical Engineering Program Faculty advisor. This option is well-suited for the student seeking to engage in deeper, open-ended inquiry into a research area, in preparation for advanced research training (e.g., Ph.D. degree) or research-focused career opportunities in a medical, academic, government, or industry laboratory setting.

Project (6 credits, Project-Based M.S.)

The Project-Based M.S. program enables students to engage in a focused, credit-based independent project experience that builds on their individual professional and academic experience. The program will facilitate development of experience, skillset, and mindset to contribute and lead in industry as engineers in a variety of biomedical engineering roles. The Project-Based M.S. program requires completion of 6 credits of **BME 597. Professional Project**, and completion of a capstone deliverable representative of their integrated project experience (e.g., poster or platform presentation, department seminar, final presentation, online portfolio). The Project may include one or more integrated project-based experiences:

1) **BME 5900. Internship or Co-op**. Students may apply for an industry-based co-op or internship, and earn academic credit while using elements of the co-op or internship as the basis for satisfying the project requirement.
2) **BME 5910. Master's Design Project**. Students may work with a faculty advisor to design a device or prototype that meets a specific set of technical objectives.
3) **BME 5920. Clinical Preceptorship**. Students may work with faculty advisors in collaboration with clinicians (including medical, dental, veterinary) to design a device, system, or other product that creates value with positive impact on clinical practice.

In addition, the following requirements must be met for both Master of Science degree programs:

- **Technical Depth Requirement (15 credits minimum)**. Thematically-related advanced engineering and science coursework in an area of technical focus within a Biomedical Engineering specialization. No more than one life sciences or regulatory course may be applied towards this requirement, and the course must be relevant to the depth area. Up to 3 credit-hours of a Thesis or Project may be designated as technical depth.
- **Seminar Requirement.** Students must take BME 591. Graduate Seminar (0 credits) and pass it twice.
- **BME Core Competencies**. In addition to meeting the specified minimum credit requirements for the degree program, all Master of Science candidates must satisfy five (5) BME Core Competencies.
  1) **Mathematics**. Understanding and ability to apply fundamental principles of mathematics (e.g., statistics, numerical methods, or computational modeling).
  2) **Life science**. Understanding and ability to apply fundamental principles of life science (e.g., cell and molecular biology, physiology).
  3) **Clinical needs analysis and design**. Ability to communicate effectively with clinical stakeholders, understanding of healthcare systems, exposure to clinical environments and practice, understanding clinical needs and recognizing opportunities to improve healthcare delivery and practice.
  4) **Regulation and controls**. Understanding of regulations and standards applied to biomedical engineering design, manufacturing, and research (e.g., medical device design regulations, FDA regulations, engineering standards, QC/QA, GMP/GLP).
  5) **Value creation, innovation, technology commercialization**. Development and practice of innovation mindset and skillset to create value and recognize opportunities for innovation in the design and development of medical technologies; commercial and clinical translation of medical innovations that impact healthcare delivery and practice.

Core Competencies.

To aid students in developing a Plan of Study, the following example courses that can fulfill each of the five (5) BME Core Competencies are provided. Alternative courses may be applied to fulfill competency requirements. Students need only take one (1) course to fulfill a given competency. Alternatively, waivers may be considered based on documented work experience, advanced degrees, majors, or minors that demonstrate advanced mastery in the core competency area. Course substitutions and waivers must be approved by the department Graduate Studies Committee. If approved, a Thesis or Project may be used to fulfil up to two (2) Competencies.

Mathematics:
MA 511. Applied Statistics for Engineers and Scientists
MA 501. Engineering Mathematics

Life Science:
BME 560. Physiology for Engineers
BME 562. Laboratory Animal Surgery
BME 564. Cell and Molecular Biology for Engineers

Regulations and Controls:
BME 532. Medical Device Regulation
BME 595D. Medical Device Design Controls

Clinical Needs Analysis and Design:
BME 592. Healthcare Systems and Clinical Practice

Value Creation, Innovation, Technology Commercialization.
BME 595V. Value Creation and Innovation in BME Thesis Research
ETR 500. Entrepreneurship and Innovation
ETR 593. Technology Commercialization: Theory, Strategy and Practice
SYS 501. Concepts of Systems Engineering
SYS 502. Business Practice

Technical Depth Specializations and Example Courses.

To aid students in developing a Plan of Study that fulfills the Technical Depth requirement, we provide the following examples. These lists are not exhaustive. Students may propose alternative courses and specializations, including thematically-related courses double-counted toward a WPI Graduate Certificate, to fulfill the Technical Depth requirement (subject to review and approval by the department Graduate Studies Committee).

Biomaterials and Tissue Engineering:
BME 531. Biomaterials in the Design of Medical Devices
BME/ME 550. Tissue Engineering
BME/ME 552. Tissue Mechanics
BME 555. BioMEMS and Tissue Microengineering
BME 583. Biomedical Microscopy and Quantitative Imaging
BME/ME 4814. Biomaterials
BME 4828. Biomaterials-Tissue Interactions

BME 4831. Drug Delivery
BME 4701. Cell and Molecular Bioengineering
CHE 521. Biochemical Engineering
MTE 509. Electron Microscopy
MTE 558. Plastics
MTE 511. Structure and Properties of Engineering Materials
MTE 512. Properties and Performance of Engineering Materials
MTE/MFE 5841. Surface Metrology
PH 561. Atomic Force Microscopy

Biomechanics and Medical Robotics:
BME 552. Tissue Mechanics
RBE 500. Foundations of Robotics
ME/RBE 501. Robot Dynamics
RBE 520. Biomechanics and Robotics
BME 553. Biomechanics of Orthopaedic Devices
RBE 580. Biomedical Robotics
BME/ME 4504. Biomechanics
BME/ME 4606. Biofluids
BME 450X. Computational Biomechanics

Additional Technical Depth Courses:
BME 523/BME 4023. Biomedical Instrumentation
BME 581. Medical Imaging
BME 4011. Biomedical Signal Analysis
BME 4201. Biomedical Imaging
ECE 503. Digital Signal Processing
ECE 5106. Modeling of Electromagnetic Fields in Electrical & Biological Systems
CS 583/BCB 503. Biological and Biomedical Database Mining
CS 534. Artificial Intelligence
CS 539. Machine Learning
CS 545/ECE 545. Digital Image Processing

For the M.E.

A minimum of 33 credit hours is required for the Master of Engineering degree. Course requirements include:

- 12 credits of biomedical engineering (any BME course except BME 560, 562, or 564)
- 3 credits of life science (e.g., BME 560, 562, 564; graduate-level biology courses)
- 3 credits of advanced mathematics (e.g., MA 501, 511; graduate-level math courses)
- 3 credits of life science or advanced mathematics
- 12 credits electives
- In addition, students are required to pass BME 591: Graduate Seminar twice.

Electives may include any WPI graduate-level engineering, physics, mathematics, biomedical engineering, or equivalent course, subject to approval of the BME Graduate Studies Committee. Students may substitute 3 to 6 credits of directed research for 3 credits of biomedical engineering and/or 3 credits of electives.

For the Ph.D.

The Ph.D. program has no formal course requirements. However, because research in the field of biomedical engineering requires a solid working knowledge of a broad range of subjects in the life sciences, engineering and mathematics, course credits must be distributed across the following categories with the noted minimums:

- 12 credits of biomedical engineering (any BME course except BME 560, 562, or 564)
- 3 credits of life science (e.g., BME 560, 562, 564; graduate-level biology courses)
- 3 credits of advanced mathematics (e.g., MA 501, 511; graduate-level math courses)
- 3 credits of life science or advanced mathematics
- 12 credits electives
- 1 credit responsible conduct of research (usually satisfied by taking BB 551: Research Integrity in the Sciences)
- Pass BME 6999. PhD Qualifying Examination
- 30 credits dissertation research (BME 699)
- In addition, students are required to pass BME 591: Graduate Seminar four times.
- The department requires acceptance of at least one full-length, first-author publication, representing original research and based on the student's dissertation work, in a peer-reviewed venue approved by the student's PhD Dissertation Examination Committee. Students have an opportunity to petition the BME Graduate Studies Committee in cases of extenuating circumstances.

Electives may include any WPI graduate-level engineering, physics, mathematics, biomedical engineering, or equivalent course, subject to approval of the BME Graduate Studies Committee. Students may substitute 3 to 6 credits of directed research for 3 credits of biomedical engineering and/or 3 credits of electives.

Laboratory Rotations.

Students in the Ph.D. program may participate in optional laboratory rotations during their first year in the program. Laboratory rotations—short periods of research experience under the direction of program faculty members—are intended to familiarize students with concepts and techniques in several different engineering and scientific fields. They allow faculty members to observe and evaluate the research aptitudes of students and permit students to evaluate the types of projects that might be developed into dissertation projects. Upon completion of each rotation, the student presents a seminar and written report on the research accomplished. Each rotation is a 3- or 4-credit course and can last a minimum of seven weeks, or up to a full semester.

Teaching Requirement.

All candidates for the Ph.D. degree must demonstrate teaching skills by preparing, presenting and evaluating a teaching exercise. This experience may involve a research seminar, lecture, demonstration or conference presentation. The presentation and associated materials are critiqued and evaluated by program faculty members. The department Graduate Studies Committee is responsible for evaluating the teaching exercise based on criteria previously defined. The teaching requirement can be fulfilled at any time, and there is no limit to the number of attempts a student may make to fulfill this requirement. It must, however, be completed successfully before the dissertation defense can be held.

Return to Table of Contents

Course Descriptions

All courses are 3 credits unless otherwise noted.

BME 523. Biomedical Instrumentation

Origins and characteristics of bioelectric signals, recording electrodes, biopotential amplifiers, basic sensors, chemical, pressure, sound, and flow transducers, noninvasive monitoring techniques and electrical safety. (Prerequisites: Circuits and electronics, control engineering or equivalent.)

BME 531. Biomaterials in the Design of Medical Devices

Biomaterials are an integral part of medical devices, implants, controlled drug delivery systems, and tissue engineered constructs. Extensive research efforts have been expended on understanding how biologic systems interact with biomaterials. Meanwhile, controversy has revolved around biomaterials and their availability as a result of the backlash to the huge liability resulting from controversies related to material and processing shortcomings of medical devices. This course specifically addresses the unique role of biomaterials in medical device design and the use of emerging biomaterials technology in medical devices. The need to understand design requirements of medical devices based on safety and efficacy will be addressed. Unexpected device failure can occur if testing fails to account for synergistic interactions from chronic loading, aqueous environments, and biologic interactions. Testing methodologies are readily available to assess accelerated effects of loading in physiologic-like environments. This combined with subchronic effects of animal implants is a potential tool in assessing durability. It is difficult to predict the chronic effects of the total biologic environment. The ultimate determination of safety comes not only from following the details of regulations, but with an understanding of potential failure modes and designs that lowers the risk of these failures. This course will evaluate biomaterials and their properties as related to the design and reliability of medical devices.

BME 532. Medical Device Regulation

This course provides an overview of regulations that guide the medical devices industry. Primary focus is on the Food, Drug and Cosmetic Act (FD&C Act) and its associated regulations. The course covers the FD&C Act, including definitions, prohibited acts, penalties and general authority. The course also covers regulations, including establishment registration, premarket approval (PMA) and current good manufacturing practices. Requirements of other federal agencies (NRC, FCC, EPA) will also be discussed.

BME 535. Medical Device Design Controls

An introduction to the fundamentals of medical device design controls from concept generation to manufacturing. Students work in teams to navigate through the medical device design and development lifecycle on various device types, fulfilling design control requirements while learning what is required to bring a concept to life in industry. Students may not receive credit if they previously completed this course as BME 595: Special Topics.

**Does not fulfil technical depth requirement.*

BME/ME 550. Tissue Engineering

This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented. (Prerequisites: A first course in biomaterials equivalent to BME/ME 4814 and a basic understanding of cell biology and physiology. Admission of undergraduate students requires the permission of the instructor.)

BME/ME 552. Tissue Mechanics

This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties, and design of medical devices and prostheses. (Prerequisite: An understanding of basic continuum mechanics.)

BME 553. Biomechanics of Orthopaedic Devices

This course will survey different types of orthopaedic implants and devices, primarily focusing on joint arthroplasty and fracture fixation methods. Topics such as: device design and function, mechanics, materials, validation and testing, failure, use cases, and regulatory requirements will be discussed. Class projects and discussions will cover contemporary topics related to the design, manufacture, and post-implantation measurement and performance evaluation of orthopaedic devices. Students may not receive credit if they previously completed this course as BME 595: Special Topics.

BME 555. BioMEMS and Tissue Microengineering

This course covers microscale biological and physical phenomena and state-of-the-art techniques to measure and manipulate these processes. Topics include scaling laws, microfabrication, machining three-dimensional microstructures, patterning biomolecules, and designing and building microfluidic devices. We will cover various biomedical problems that can be addressed with microfabrication technology and their associated engineering challenges, with special emphasis on applications related to quantitative biology, tissue microengineering, controlling the cellular microenvironment, and clinical/diagnostic lab-on-a-chip devices.

BME 560. Physiology for Engineers

An introduction to fundamental principles in cell biology and physiology designed to provide the necessary background for advanced work in biomedical engineering. Quantitative methods of engineering and the physical sciences are stressed. Topics include cell biology, DNA technology and the physiology of major organ systems.

NOTE: This course can be used to satisfy a life science requirement in the biomedical engineering program. It cannot be used to satisfy a biomedical engineering course requirement.

BME 562. Laboratory Animal Surgery

A study of anesthesia, surgical techniques and postoperative care in small laboratory animals. Anatomy and physiology of species used included as needed. Class limited to 15 students. Approximately 15 surgical exercises are performed by each student. (Prerequisite: Graduate standing. Admission of undergraduate students requires the permission of the department head and the instructor.)

NOTE: This course can be used to satisfy a life science requirement in the biomedical engineering program. It cannot be used to satisfy a biomedical engineering course requirement.

BME 564. Cell and Molecular Biology for Engineers

An advanced course in cell and molecular biology for engineering graduate students, with an emphasis on molecular approaches to measuring and manipulating cell responses for biomedical engineering applications. Course topics will include in depth exploration of the molecular basis of cellular function, including protein biochemistry, signal transduction, cell-extracellular matrix interactions and regulation of gene expression. Tools and techniques used in modern cell and molecular biology will be discussed in the context of current research literature.

NOTE: This course can be used to satisfy a life science requirement in the graduate biomedical engineering program. It cannot be used to satisfy a biomedical engineering course requirement (undergraduate or graduate).

BME 581. Medical Imaging Systems

Overview of the physics of medical image analysis. Topics covered include X-Ray tubes, fluoroscopic screens, image intensifiers; nuclear medicine; ultrasound; computer tomography; nuclear magnetic resonance imaging. Image quality of each modality is described mathematically, using linear systems theory (Fourier transforms, convolutions). (Prerequisite: Signal analysis course BME/ECE 4011 or equivalent.)

BME 583. Biomedical Microscopy and Quantitative Imaging

This course introduces fundamental principles of biomedical imaging focused on quantitative microscopy. Topics include physical basis of light microscopy, fluorescence microscopy, live cell imaging and computer vision algorithms. Advanced topics include 3D imaging (confocal, light sheet, 2-photon), super-resolution, sample preparation, and equipment considerations. Selected topics in medical imaging (CT, MRI, ultrasound) may be included, with hands-on instruction on commercial and student-built systems.

NOTE: Students who received credit for BME 581 in Spring 2016 may not also receive credit for BME 583.

BME 591. Graduate Seminar

(0 credits)

Topics in biomedical engineering are presented both by authorities in the field and graduate students in the program. Provides a forum for the communication of current research and an opportunity for graduate students to prepare and deliver oral presentations. Students may meet the attendance requirement for this course in several ways, including attendance at weekly biomedical engineering seminars on the WPI campus, attendance at similar seminar courses at other universities or biotech firms, attendance at appropriate conferences, meetings or symposia, or in any other way deemed appropriate by the course instructor.

BME 5910. Master's Design Project

(0 cr., pass/fail grading)

A Master's Design Project experience is designed to enhance the professional development of the graduate student who wishes to focus on design. Master's Design Projects may be pursued within any laboratory or other organization within or external to WPI. The project deliverable must be the design or prototype of a device. This course is subject to approval by the departmental designee and sponsor.

BME 592. Healthcare Systems and Clinical Practice

(1 cr., letter grading)

This course fulfills the Clinical Competency requirement in Biomedical Engineering. The course will follow a seminar format, with healthcare professionals, faculty, and medical device industry experts serving as invited lecturers and case study presenters. The course is designed to introduce BME graduate students to clinical environments and practice, healthcare delivery systems, and communication with clinical stakeholders.

BME 5920. Master's Clinical Preceptorship

(0 cr., pass/fail grading)

A Master's Clinical Preceptorship experience is designed to enhance the professional development of the graduate student who wishes to focus on clinical applications of BME. Clinical Preceptorships may be pursued at any organization providing clinical care, such as hospitals, physician offices, dentists, and veterinary clinics. This course is subject to approval by the departmental designee and external organization.

BME 593. Scientific Communication

Clear oral, written, and graphical communication of scientific methods and data is an essential skill for success, both in research and in industry. This course will cover aspects of scientific communication including: scientific manuscript preparation and the peer review process, technical report organization, graphical presentation of quantitative data, and oral presentation of scientific information. Organization and clarity will be emphasized in communicating scientific methods, results, and interpretation. Students will complete regular writing and presentation assignments and participate in peer critique sessions. Students will complete an original research article, review article, or technical report as a final project. Students may not receive credit if they previously completed this course as BME 595: Special Topics.

**Does not fulfil technical depth requirement.*

BME 594. Biomedical Engineering Journal Club

(1 credit)

This course will cover different topics in biomedical engineering research, both basic and translational. Enrolled students read and discuss the literature in relevant topics, which may include biomaterials, drug delivery, tissue engineering, cardiovascular engineering, mechanobiology, quantitative imaging, instrumentation, computational biomechanics, injury and rehabilitative biomechanics, or any focused topic related to biomedical engineering. The objectives of the course are for students to learn about current topics within a focused area of biomedical engineering, to improve their ability to critically review literature, and develop their technical presentation skills. Multiple sections of biomedical engineering journal club focused on different research topics may be offered each semester. (Pre-requisite: Master's or Ph.D. student in biomedical engineering or a related discipline).

Biomedical engineering graduate students may take up to 3 credits of BME 594 to satisfy Biomedical Engineering or Elective course credit to meet graduate program distribution requirements.

NOTE: This course cannot be used to satisfy Biomedical Engineering or Engineering elective credit to meet undergraduate program distribution requirements.

BME 595. Special Topics in Biomedical Engineering

(1-3 credits)

Topics in biomedical engineering. Presentations and discussions of the current literature in an area of biomedical engineering.

BME 596. Research Seminar

Presentations on current biomedical engineering research.

BME 597. BME Professional Project

(up to 6 cr., letter grading)

This course fulfills the requirement for a Project-based Master's of Science degree in Biomedical Engineering. The Professional Project is carried out in combination with an industry experience, clinical preceptorship, or design project, with oversight and input from a WPI core faculty member. Goals and objectives for the project must be documented and approved by the core faculty member, in consultation with the sponsor. To complete the project, a capstone deliverable, representative of the experience, is required. Examples of deliverables include a device prototype, public presentation, online portfolio, or another format appropriate for the specific project. Students should register for a total of 6 credits of this course, in combination with 0 credits of BME 5900 (Master's Graduate Internship Experience), BME 5910 (Master's Design Project), or BME 5920 (Master's Clinical Preceptorship).

BME 598. Directed Research

Students may register for Directed Research to fulfill graduate research rotation (e.g. Master's students seeking a thesis lab) or independent, mentored graduate research and projects. BME graduate students may apply up to 3 credits of BME 598 as BME course credit and an additional 3 credits of BME 598 credit to fulfill elective, laboratory rotation, or independent project credit. BME 598 credit used for laboratory rotations may be converted to BME 599 or BME 699 credit for qualified graduate students who remain in the rotation laboratory for their thesis or dissertation research. (Pre-requisite: Master's or Ph.D. student in biomedical engineering).

BME 599. Master's Thesis

Graduate students enrolled in the thesis-based (Master of Science, M.S.) program must complete 6 credits total and successfully defend and submit a Master's thesis by the posted deadlines. (Pre-requisite: Master's thesis student in biomedical engineering).

BME 698. Laboratory Rotation in Biomedical Engineering

Offered fall, spring and summer for students doing laboratory rotations on the WPI campus. Available for 3 or 4 credits. (Prerequisite: Ph.D. student in biomedical engineering.)

Return to Table of Contents

BME 699. Ph.D. Dissertation

All Ph.D. students must complete 30 credits of dissertation research to fulfill Ph.D. degree requirements. (Pre-requisite: Student has passed the Biomedical Engineering Ph.D. Qualifying Examination).

BME 6999. Ph.D. Qualifying Examination

This examination is a defense of an original research proposal, made before a qualifying examination committee (QEC) representative of the areas of specialization. The examination is used to evaluate the ability of the student to pose meaningful engineering and scientific questions, to propose experimental methods for answering those questions, and to interpret the validity and significance of probably outcomes of these experiments. It is also used to test a student's comprehension and understanding of their formal coursework in life sciences, biomedical engineering and mathematics.

Possible outcomes of the qualifying examination are:

1 Unconditional Pass – The candidate satisfied a majority of the QEC according to all criteria.
2. Conditional Pass with specific course work to address a specific deficiency – The candidate satisfied a majority of the QEC with the exception of a particular weakness in one of the areas of specialization. The QEC is confident that the weakness can be corrected by the candidate taking a particular course specific to the area of weakness. Upon completion of the designated course with a "B" grade or higher, the student advances to PhD candidacy.
3. Fail with an opportunity to retake within 6 months – The QEC determined that the candidate had several weaknesses. However, the majority of the QEC determined that the student has the potential to be a successful PhD candidate and could address the weaknesses. In this case, the student will have an opportunity to repeat the exam, which must be accomplished with 6 months of the original exam. The second exam only has two possible outcomes; unconditional pass, or fail without opportunity to retake the exam.

Students are required to pass the Ph.D. qualifying examination no later than the fifth semester after formal admittance to the Ph.D. program. Admission to Ph.D. candidacy is officially conferred upon students who have completed their course credit requirements, exclusive of dissertation research credit, and passed the Ph.D. qualifying examination.

Robert A. Foisie School of Business

business.wpi.edu

Faculty

S. Taylor, Professor and Dean, ad Interim; Ph.D., Boston College; organizational aesthetics, reflective practice, leadership.

D. Strong, Professor and Department Head; Ph.D., Carnegie-Mellon University; advanced information technologies, such as enterprise systems, and their use in organizations, MIS quality issues, with primary focus on data and information quality.

K. Ching, Assistant Professor; Ph.D., Massachusetts Institute of Technology; entrepreneurial strategy, economics of science and innovation, science and innovation policy, digitization, data science.

S. Djamasbi, Professor and MSIUX Program Director; Ph.D., University of Hawaii at Manoa; decision making, decision support systems, information overload, decision making under crisis, affect and decision making.

M. B. Elmes, Professor and MBA/MSMG Program Director; Ph.D., Syracuse University; workplace resistance and ideological control, critical perspectives on spirituality-in-the-workplace, implementation of IT in organizations, organizations in the natural environment, narrative and aesthetic perspectives on organizational phenomena, psychodynamics of group and intergroup behavior.

E. Gonsalves, Professor of Practice in Marketing; M.S. in Management, Worcester Polytechnic Institute; marketing, strategy, international business

A. Hall-Phillips, Associate Professor and Undergraduate Program Director; Ph.D., Purdue University; consumer behavior, business-to-business marketing, small business.

H. Higgins, Professor; Ph.D., Georgia State University; financial accounting, focusing on earnings expectation and international accounting.

F. Hoy, Beswick Professor of Entrepreneurship; Director, Collaborative for Entrepreneurship and Innovation; Ph.D., Texas A&M University; entrepreneurship, family and small business management, strategy, international entrepreneurship.

S. A. Johnson, Professor and MSOAM Program Director; Ph.D., Cornell University; lean process design, enterprise engineering, process analysis and modeling, reverse logistics.

R. Konrad, Associate Professor; Ph.D., Purdue University; health systems engineering, patient flow optimization, health informatics, industrial engineering.

N. Kordzadeh, Assistant Professor; Ph.D., University of Texas at San Antonio; health informatics and analytics, social informatics and web 2.0, information privacy, applications of GIS in business and health care

E. Lingo, Assistant Professor; Ph.D., Harvard University; organizational studies, leadership, creativity.

F. Miller, Associate Professor; Ph.D., Michigan State University; managerial accounting and performance management.

F. Reshadi, Assistant Professor; Ph.D., West Virginia University; marketing, social media and social influence, financial and health-care decision making.

J. Ryan, Associate Teaching Professor; Ph.D., Auburn University; management information systems, health care I.T.

S. Saberi, Assistant Professor; Ph.D., University of Massachusetts-Amherst; operations, industrial engineering, supply chain management.

J. Sarkis, Professor and MSSCM Program Director; Ph.D., State University of New York at Buffalo; operations management, green supply chain management, sustainability.

R. Sarnie, Professor of Practice; MBA, Suffolk University; finance, financial technology.

J. Schaufeld, Professor of Practice in Entrepreneurship; MBA, Northeastern University; entrepreneurship, technology commercialization, business acquisition and development.

P. Shah, Associate Professor and MSMI Program Director; Ph.D., Texas Tech University; marketing, brand strategy, product disposal strategy.

W. Towner, Associate Teaching Professor; Ph.D., Worcester Polytechnic Institute; operations management, lean manufacturing, six-sigma.

A. Trapp, Associate Professor; Ph.D., University of Pittsburgh; industrial engineering, combinatorial optimization, stochastic programming, operations research.

B. Tulu, Associate Professor; Ph.D., Claremont Graduate University; medical informatics, V.O.I.P., information security, telecommunications and networking, systems analysis and design.

E. V. Wilson, Associate Teaching Professor; Ph.D., University of Colorado; information systems, cognitive science.

S. Worthington, Visiting Assistant Professor; Ph.D., Worcester Polytechnic Institute; digital and social media marketing, entrepreneurship, technology commercialization.

J. Zhu, Professor and Ph.D. Program Director; Ph.D., University of Massachusetts; information technology and productivity, e-business, performance evaluation and benchmarking.

Department Research

In addition to teaching, School of Business faculty are involved in a variety of sponsored research and consulting work. A sampling of current research includes: quality control in information-handling processes, supply chain management, decision/risk analysis, conflict management, capacity planning, international accounting differences, strategy and new venture teams, family and small business management, user experience, and health systems innovation.

Return to Table of Contents

The Collaborative for Entrepreneurship and Innovation

The Collaborative for Entrepreneurship and Innovation (CEI) is a university-wide program of the Robert A. Foisie School of Business, designed to inspire and nurture people to discover, create and commercialize new technology-based products, services and organizations. It coordinates all entrepreneurship-related activity within FBS, including graduate and undergraduate courses; a student-run entrepreneurship club; the Coleman Fellows program; and endowed competitions. Please call 508-831-5761 or email cei@wpi.edu for more information.

Programs of Study

The interaction between business and technology drives every aspect of our Graduate Business Programs. We believe the future of business lies in leveraging the power of technology to optimize business opportunities. WPI stays ahead of the curve, giving students the ability to combine sound strategies with cutting edge innovation, and the confidence to contribute meaningfully within a global competitive environment. The superior record of our graduates' successes highlight why WPI enjoys a nationally-recognized reputation as one of the most respected names in technology-based business education.

WPI offers a variety of graduate business programs focusing on the integration of business and technology. The Master of Business Administration (MBA) is a highly integrated, applications-oriented program that provides students with both the 'big picture' perspective required of successful upper-level managers and the hands-on knowledge needed to meet the daily demands in the workplace. WPI's focus on the management of technology comes from the recognition that rapidly changing technology is driving the pace of business.

Students enjoy extensive opportunities to expand their networks through associations with their peers and leading high-tech organizations. They also benefit from the latest available technologies and one of the nation's most wired universities. The program's strong emphasis on interpersonal and communications skills prepares students to be leaders in any organization, and the global threads throughout the curriculum ensure that students understand the global imperative facing all businesses. Whether dealing with information technology, biotechnology, financial markets, information security, supply chain management, manufacturing, or a host of other technology-oriented industries, the real world is part of the classroom, and students explore up-to-the-minute challenges faced by actual companies, through hands-on projects and teamwork. WPI promotes an active learning process, designed to develop the very best managers, leaders and executives in a technology-dependent world.

Graduate Certificates

Graduate business certificates are designed for technical and business professionals seeking focused, in-depth knowledge within a specific area of technology management. Certificates include: Financial Technology; Health Systems Innovation; Information Security Management; Information Technology; Innovation with User Experience; Marketing Innovation; Supply Chain Analytics; and Supply Chain Essentials. Each certificate consists of 4 courses, which may be double-counted toward a related master's degree. Students may also customize their own graduate business certificate. For more information, please see http://business.wpi.edu/+certificates

Master of Business Administration (MBA)

WPI's MBA program is aimed at STEM professionals seeking the skills to strategically manage organizations. The curriculum features the core business disciplines in the context of tech-driven environments; courses to lead and inspire people; a focus on technology commercialization and the latest developments in a variety of STEM industries; and culminates in a team-based capstone project. See table 1 for the MBA Curriculum.

Table 1: MBA Curriculum

CURRICULUM	CREDITS
Required: 15 courses	39
ACC 500 Accounting and Finance Fundamentals	1
ACC 502 Financial Intelligence and Strategic Decision-Making	2
BUS 500 Business Law, Ethics, & Soc. Responsibility	3
BUS 590 Strategy in Technology-based Organizations	3
BUS 595 The Edge of Technology in STEM Industries	3
BUS 599 Capstone Project	3
ETR 593 Technology Commercialization: Theory, Strategy and Practice	3
FIN 503 Financial Decision-Making for Value Creation	3
FIN 504 Financial Statement Analysis and Valuation	2
ACC 505 Performance Measurement and Management	1
MIS 500 Innovating with Information Systems	3
MKT 500 Marketing Strategy	3
OBC 505 Teaming and Organizing for Innovation	3
OBC 506 The Heart of Leadership: Power, Reflection, and Interpersonal Skills	3
OIE 501 Designing Operations for Competitive Advantage	3
Choice of 1 course from:	
OBC533 Negotiations, or OBC537 Leading Change	3
2 Electives	6
Total: 18 courses	48

MBA Options

Students pursue the WPI MBA on a full- or part-time basis via a blended format that mixes online learning with 2 full-day on-campus face-to-face meetings per course per semester. Students join one of WPI's MBA Cohorts and may complete the MBA in 32 or 64 months with a defined group of their peers. For more information on MBA options, please see http://business.wpi.edu/+mba.

M.S. in Business Analytics (MSBA)

The demand for knowledgeable professionals who understand both data analytics and business needs continues to increase. The MSBA program provides a solid foundation in business analytics, with applications in a variety of business areas, plus a real-world, team-based project, which ensures that students are prepared to be successful in a data-driven, technological business environment.

MSBA students must complete a three-course core as follows:

- MIS 584 Business Intelligence
- OIE 552 Modeling and Optimizing Processes
- MIS 502 Data Management for Analytics

MSBA students must complete two three-course specialties, selected from the following specialties:

- Specialty in Advanced Business Analytics Methods
  - MIS 587 Business Applications in Machine Learning
  - OIE 559 Optimization for Business Analytics
  - MKT 562 Marketing Research
- Specialty in Marketing Analytics:
  - Select one of the following:
    - MKT 500 Marketing Strategy (recommended for students with no marketing background)
    - MKT 561 Consumer Behavior and Analytics
  - MKT 565 Digital Marketing
  - MKT 568 Data Mining Business Applications
- Specialty in Operations Analytics, select 3 of the following 5 courses:
  - OIE 501 Designing Operations for Competitive Advantage (recommended for students with no operations background)
  - OIE 542 Risk Management and Decision Analysis
  - OIE 544 Supply Chain Analysis and Design
  - OIE 548 Performance Analytics
  - OIE 558 Designing and Managing Lean Six Sigma Processes
- Specialty in Financial Analytics:
  - ACC 500 Accounting and Finance Fundamentals (1 credit) plus ACC 502 Financial Intelligence and Strategic Decision-Making (2 credits)
  - FIN 500 Financial Information and Management
  - FIN 522 Financial Institutions, Markets, and Technology
- Note: Additional specialties are likely to be developed in the future.

MSBA students must complete a two-course capstone project experience as follows:

- OBC 505 Teaming and Organizing for Innovation
- BUS 596 Master of Science Capstone Project

Additional Recommendations:

- On-campus, international students are encouraged to complete up to three additional credits of internship to ensure their readiness for employment in the U.S.

M.S. in Information Technology (MSIT)

The demand for knowledgeable IT professionals who understand business has never been greater. The MSIT program guarantees a solid foundation in information technology and business analytics, with a wide range of cutting-edge concentrations, and how these technologies and analytics tools can best be used in a variety of business applications. The program covers principles of business, people and technology that are critical to success in technology-driven environments.

MSIT students must complete a three-course core as follows:

- MIS 581 Policy and Strategy for IT and Analytics
- MIS 584 Business Intelligence
- MIS 502 Data Management for Analytics

MSIT students must complete two three-course specialties, selected from the following specialties:

- Specialty in Information Systems Design
  - MIS 571 Database Applications Design and Development
  - MIS 582 Information Security Management
  - MIS 585 User Experience Design
- Specialty in Data Analytics
  - MIS 587 Business Applications in Machine Learning
  - MKT 568 Data Mining Business Applications

  Select 1 of the following:
  - MKT 565 Digital Marketing
  - MKT 562 Marketing Research
- Specialty in Digital Transformation
  - MIS 500 Innovating with Information Systems

  Select one of the following:
  - OIE 501 Designing Operations for Competitive Advantage (recommended for students with no operations background)
  - OIE 544 Supply Chain Analysis and Design
  - OIE 558 Designing and Managing Lean Six Sigma Processes

  Select one of the following:
  - MIS 576 Project Management
  - OBC 533 Negotiations
  - OBC 537 Change Management
- Specialty in IT User Experience
  - MKT 561 Consumer Behavior and Analytics
  - MIS 583 User Experience Applications
  - MIS 586 User Experience Research Methods
- Additional specialties are likely to be developed in the future

MSIT students must complete a two-course capstone project experience as follows:

- OBC 505 Teaming and Organizing for Innovation
- BUS 596 Master of Science Capstone Project

Additional Recommendations:

- On-campus, international students are encouraged to complete up to three additional credits of internship to ensure their readiness for employment in the U.S.

Return to Table of Contents

M.S. in Innovation with User Experience (MSIUX)

Rapid advances in science and engineering allow companies to develop increasingly sophisticated IT products. As the IT industry matures, competition is increasingly shifting toward providing outstanding user experiences (UX). Innovation with UX is becoming essential in developing IT products and services that can maintain competitive advantage in the marketplace. The Foisie Business School has world-class expertise and resources in UX and is ideally positioned to prepare students as UX professionals and set them on a path to take on leaderships positions such as chief experience officers (CXO).

9 required core courses (27 credits)
- MIS 585 UX Design
- MIS 586 UX Research Methods
- MIS 583 UX Applications
- MIS 571 Database Applications Design and Development
- MIS 584 Business Intelligence

2 marketing core courses from the following list
- MKT 500 Marketing Strategy
- MKT 561 Consumer Behavior and Analytics
- MKT 568 Data Mining Business Applications

1 Business core course from the following list
- OBC 505 Teaming and Organizing for Innovation
- OBC 533 Negotiations

1 Finance core course from the following list
- FIN 500 Financial Information and Management
- ACC 500 Accounting and Finance Fundamentals (1 cr.) & ACC 502 Financial Intelligence and Strategic Decision-Making (2 cr.)

3 electives from the following list (9 credits)
- Design courses:
- UX Research Project I (Advisor approval is required)
- UX Research Project II (Advisor approval is required)
- MIS 573 System Design and Development
- IMGD 5000 Game Design Studio
- IMGD 5300 Design of Interactive Experiences

Business courses:
- Any of the above marketing or business core courses not taken for the core requirement
- ETR 500 Entrepreneurship and Innovation
- ETR 593 Technology Commercialization: Theory, Strategy and Practice
- MKT 562 Marketing Research
- MKT 565 Digital Marketing
- OIE 501 Designing Operations for Competitive Advantage
- OIE 552 Modeling and Optimizing Processes
- OIE 556 Health System Modeling and Improvement
- BUS 5900 Internship (no more than 3 credits)

Technical courses:
- CS 528 Mobile and Ubiquitous Computing
- CS 546 Human Computer Interaction
- CS 573 Data Visualization
- CS 5007 Introduction to Programming Concepts, Data Structures and Algorithms
- DS 501 Introduction to Data Science
- DS 502 Statistical Methods for Data Science
- MA 511 Applied Statistics for Engineers & Scientists

M.S. in Management (MSMG)

The MSMG offers students a flexible yet focused program that will improve business skills while excelling in technology-based organizations. The MSMG also provides a compelling pathway to an MBA, recognizing the value of work experience. Upon earning the MSMG, and after 2 – 6 years of professional experience, students may return to WPI to complete the requirements for an MBA with just 27 additional credits, including the hallmark project experience of WPI (MBA admission required).

- MSMG students complete the following 11 courses:
- ACC 500 Accounting and Finance Fundamentals (1 cr.)
- ACC 502 Financial Intelligence and Strategic Decision-Making (2 cr.)
- BUS 500 Business Law, Ethics, and Social Responsibility
- FIN 503 Financial Decision-Making for Value Creation
- MIS 500 Innovating with Information Systems
- MKT 500 Marketing Strategy
- OBC 505 Teaming and Organizing for Innovation
- OIE 501 Designing Operations for Competitive Advantage
- 3 Electives

M.S. in Marketing and Innovation (MSMI)

A highly specialized program specifically designed for individuals employed in or aspiring to work in marketing positions and/or positions responsible for innovation within technology- oriented environments. The M.S. in marketing and innovation features 6 required courses including:
- ETR 500 Entrepreneurship and Innovation
- FIN 500 Financial Information and Management
- MKT 500 Marketing Strategy
- MKT 562 Marketing Research
- MKT 565 Digital Marketing
- OBC 505 Teaming and Organizing for Innovation

Students then select 4 electives from the following list:
- ETR 596 Selling and Sales
- MIS 583 User Experience Applications
- MIS 585 User Experience Design
- MKT 561 Consumer Behavior and Analytics
- MKT 564 Global Technology Marketing
- MKT 567 Integrated Marketing Communications
- MKT 568 Data Mining Business Applications
- MKT 569 Product and Brand Management
- OIE 544 Supply Chain Analysis and Design

Students round out their MSMI with 2 free electives, which may include courses outside of business and a maximum of 3 credits of internship.

Return to Table of Contents

M.S. in Operations Analytics and Management (MSOAM)

Today's business environments deal constantly with changes requiring leadership for operational solutions. The MSOAM is a comprehensive Operations Management program that provides students with the ability to customize their program with a broad selection of electives focusing in-depth on issues in operations management and related business areas.

MSOAM students complete the following required courses:

- OBC 505 Teaming and Organizing for Innovation
- OIE 501 Designing Operations for Competitive Advantage
- OIE 542 Risk Management and Decision Analysis
- OIE 544 Supply Chain Analysis and Design
- OIE 552 Modeling and Optimizing Processes
- OIE 554 Global Operations Strategy
- OIE 558 Designing and Managing Lean Six Sigma Processes

Choose 1 *(the other may be used as an elective)*:

- MIS 500 Innovating with Information Systems
- MIS 571 Database Applications Design and Development

Students then select 4 electives from the following list:

- BUS 522 Global Business Experience
- BUS 545 Introduction to Health Systems
- BUS 546 Managing Technological Innovation
- BUS 547 Energy Management
- BUS 5900 Internship
- MIS 573 System Design and Development
- MIS 576 Project Management
- MIS 581 Policy and Strategy for I.T. and Analytics
- MIS 582 Information Security Management
- MIS 583 User Experience Applications
- MIS 584 Business Intelligence
- MIS 585 User Experience Design
- MKT 568 Data Mining Business Applications
- OBC 506 The Heart of Leadership: Power, Reflection, and Interpersonal Skills
- OBC 533 Negotiations
- OBC 536 Organizational Design
- OBC 537 Leading Change
- OIE 548 Performance Analytics
- OIE 553 Global Purchasing and Logistics
- OIE 556 Health Systems Modeling and Improvement
- OIE 559 Optimization for Business Analytics

M.S. in Supply Chain Management (MSSCM)

Organizations in virtually every industry rely on intricate supply chains that globally manage goods and services demands. Synchronizing the flow of products, information, and funds is becoming increasingly complex with products that move across continents daily and deadlines that directly affect a company's profitability. This MSSCM program is designed to deliver an intensive analytical curriculum and to embrace various experiential learning opportunities to develop students' interdisciplinary skills necessary for developing career choices and leaderships in the field.

MSSCM students must complete the following 7 required courses:

- OIE 501 Designing Operations for Competitive Advantage
- OIE 544: Supply Chain Analysis and Design
- OIE 553: Global Purchasing and Logistics
- MIS 576: Project Management
- MKT 561: Consumer Behavior and Analytics
- OBC 533: Negotiations
- OIE 597: Supply Chain Consulting Project

For those who have NOT taken finance or accounting as an undergraduate or elsewhere or who cannot demonstrate sufficient financial experience, choose 1 of the following:

- ACC 500 Accounting and Finance Fundamentals (1 cr.) and ACC 502 Financial Intelligence and Srategic Decision-Making (2 cr.)
- FIN 500: Financial Information and Management
- OIE 598: Special Topic – Financial Analysis of Supply Chains

Students then select 4 electives from the following list:

- MKT 565: Digital Marketing
- MKT 568: Data Mining Business Applications
- OIE 542 Risk Management and Decision Analysis
- OIE 559: Optimization for Business Analytics
- OIE 598: Special Topic – Sustainable Supply Chain & Operations Management
- OIE 598: Special Topic – Materials Management in Supply Chains
- OIE 598: Special Topic – Supply Chain Simulation Modeling and Analysis
- BUS 598: Special Topic – Supply Chain Performance Analysis
- OIE 599: Supply Chain Research
- 1 course in other Business discipline or outside Business

Combined B.S./M.S. Program

This program is available to WPI undergraduate students wishing to combine one of the Foisie School of Business' M.S. degrees with their B.S. A separate and complete application to the M.S. program must be submitted. Admission to the Combined Program is determined by the School of Business. With careful planning, both degrees may be completed within the student's four years of undergraduate study.

It is recommended that the M.S. application be submitted at the end of the student's sophomore year of undergraduate study. A student in the Combined Program continues to be registered as an undergraduate until the bachelor's degree is awarded.

To obtain a bachelor's degree via the Combined Program, the student must satisfy all requirements for the bachelor's degree, including distribution and project requirements. To obtain an M.S. via the Combined Program, the student must satisfy all M.S. degree requirements. Note: no undergraduate credit may be counted toward a graduate business degree.

Please refer to the section on the Combined Programs or contact the executive director of business programs for more information.

Return to Table of Contents

Admission Requirements

For the Master's program, applicants should have the analytic aptitude and academic preparation necessary to complete a technology-oriented business program. This includes a minimum of three semesters of college level math or two semesters of college level calculus. Applicants to the MSIT are also required to have a prior college-level programming course.

Applicants must have the earned equivalent of a four-year U.S. bachelor's degree to be considered for admission. Admission decisions are based upon all the information required from the applicant. GMAT or GRE required; waived for WPI students and alumni with a cumulative undergraduate GPA of 3.0+. Waivers may be considered based on work experience and/or advanced degrees.

For the Ph.D. an applicant must be a graduate of an accredited U.S. college or university or an approved foreign equivalent institution, and have earned a grade point average of 3.0 or better in all prior undergraduate and graduate studies. A student with a master's degree will be expected to have successfully demonstrated graduate level knowledge in a traditional business discipline such as Accounting, Finance, Marketing, Organizational Behavior, Entrepreneurship, Information Technology, or Operations Management; or in a discipline that is relevant to the student's proposed concentration. Additionally, the applicant will demonstrate undergraduate competency in Calculus, Statistics and/or Micro/Macro Economics.

Locations

Tailored to meet the challenges of working professionals, WPI offers full- and part-time graduate business study at our campus in Worcester, Massachusetts, as well as world-wide via our Blended and online courses.

Degree Requirements

For the M.B.A.

48 credits distributed as follows (all courses are 3 credits unless otherwise noted):

- **15 Required Courses**
  ACC 500 (1 cr), ACC 502 (2 cr), ACC 505 (1 cr), BUS 500, BUS 590, BUS 595, BUS 599, ETR 593, FIN 503, FIN 504 (2 cr), MIS 500, MKT 500, OBC 505, OBC 506, OIE 501
- **Choose 1**
  OBC 533, OBC 537
- **2 Elective Courses**

For the M.S. in Business Analytics (MSBA)

33 credits, distributed as follows (credits in parentheses):

- **3 Required Courses**
  MIS 502, MIS 584, OIE 552 (9 credits)
- **Choose 2, 3-course Specializations (18 credits)**
  Advanced Business Analytics Methods
  MIS 587, MKT 562, OIE 559
  Marketing Analytics
  MKT 500 or MKT 561; MKT 565, MKT 568
  Operations Analytics (choose 3)
  OIE 501, OIE 542, OIE 544, OIE 548, OIE 558
  Financial Analytics
  ACC 500 & ACC 502, FIN 500, FIN 522
- **Capstone**
  BUS 596, OBC 505 (6 credits)

For the M.S. in Information Technology (MSIT)

33 credits, distributed as follows (credits in parentheses):

- **3 Required Courses**
  MIS 502, MIS 581, MIS 584 (9 credits)
- **Choose 2, 3-course Specializations (18 credits)**
  Information Systems Design
  MIS 571, MIS 582, MIS 585
  Data Analytics
  MIS 587, MKT 568; 1 of the following: MKT 562 or MKT 565
  Digital Transformation
  MIS 500; 1 of the following: OIE 501, OIE 544, OIE 558; 1 of the following: MIS 576, OBC 533, OBC 537
  I.T. User Experience
  MIS 583, MIS 586, MKT 561
- **Capstone**
  BUS 596, OBC 505 (6 credits)

For the M.S. in Innovation with User Experience (MSIUX)

36 credits distributed as follows (credits in parentheses):

- **5 Required Courses**
  MIS 571, MIS 583, MIS 584, MIS 585, MIS 586 (15 credits)
- **Choose 2 Marketing Core Courses**
  MKT 500, MKT 561, MKT 568 (6 credits)
- **Choose 1 Business Core Course**
  OBC 505, OBC 533 (3 credits)
- **Choose 1 Finance Core Course**
  FIN 500, ACC 500/ACC 502 (3 credits)
- **Choose 3 Electives** (9 credits)
  Design Courses:
  IMGD 5000, IMGD 5300, MIS 573, UX Research Project
  Business Courses:
  ETR 500, ETR 593, MKT 562, MKT 565, OIE 501, OIE 552, OIE 556, BUS 5900
  Design Courses:
  CS 5007, CS 528, CS 546, CS 573, DS 501, DS 502, MA 511

For the M.S. in Management (MSMG)

30 credits, distributed as follows (credits in parentheses):

- **8 Required Courses**
  ACC 500, ACC 502, BUS 500, FIN 503, MIS 500, MKT 500, OBC 505, OIE 501 (21 credits)
- **3 Elective Courses**
  (9 credits)

For the M.S. in Marketing and Innovation (MSMI)

36 credits, distributed as follows (credits in parentheses):

- **6 Required Courses**
  ETR 500, FIN 500, MKT 500, MKT 562, MKT 565, OBC 505 (18 credits)
- **4 Elective Courses**
  Selected from the following:
  ETR 596, MIS 583, MIS 585, MKT 561, MKT 564, MKT 567, MKT 568, MKT 569, OIE 544 (12 credits)
- **2 Free Electives** which may be any graduate course at WPI and a maximum of 3 credits of internship (6 credits)

Return to Table of Contents

For the M.S. in Operations Analytics and Management (MSOAM)

36 credits, distributed as follows (credits in parentheses):

- **7 Required Courses**
  OBC 505, OIE 501, OIE 542, OIE 544, OIE 552, OIE 554, OIE 558 (21 credits)
- **Choose 1**
  MIS 500, MIS 571 (3 credits)
- **4 Elective Courses**
  Selected from the following::
  BUS 222, BUS 545, BUS 546, BUS 547, BUS 5900, MIS 573, MIS 576, MIS 581, MIS 582, MIS 583, MIS 584, MIS 585, MKT 568, OBC 506, OBC 533, OBC 536, OBC 537, OIE 548, OIE 553, OIE 556, OIE 559

For the M.S. in Supply Chain Management (MSSCM)

36 credits, distributed as follows (credits in parentheses):

- **7 Required Courses**
  OIE 501, OIE 544, OIE 553, OIE 597, MIS 576, MKT 561, OBC 533 (21 credits)
- **Choose 1**
  ACC 500/ACC 502, FIN 500, OIE 598 (3 credits)
- **Choose 4**
  BUS 598, MKT 565, MKT 568, OIE 542, OIE 559, OIE 598, SCM 599, 1 free elective (12 credits)

Ph.D. Program

The course of study leading to the Ph.D. degree in Business Administration requires the completion of 90 credits beyond the bachelor's degree, or 60 credits beyond the master's degree. For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

Coursework:	
Courses in B.A. (incl. Special Topics and ISP)	15 credits
Courses in or outside of B.A.	15 credits
Dissertation Research (BUS 699)	30 credits
Other:	30 credits
Additional coursework	
Additional Dissertation Research (BUS 699)	
Supplemental Research (BUS 698)	
TOTAL	**90 credits**

For students proceeding from master's to Ph.D. degree, the 60 credits should be distributed as follows:

Coursework:	
Courses in B.A. (incl. Special Topics and ISP)	12 credits
Dissertation Research (BUS 699)	30 credits
Other:	18 credits
Additional coursework	
Additional Dissertation Research (BUS 699)	
Supplemental Research (BUS 698)	
TOTAL	**60 credits**

In either case, the result of the dissertation research must be a completed doctoral dissertation. Only after admission to candidacy may a student receive credit toward dissertation research under *BUS 699*. Prior to admission to candidacy, a student may receive up to 18 credits of pre-dissertation research under *BUS 698*. All full-time students are required to register for the zero credit *BUS 691 Graduate Seminar* every semester.

Students formally accepted as a doctoral candidate must select a concentration in which to pursue their dissertation research. The available concentrations are listed below:

Entrepreneurship concentration: Entrepreneurship encompasses opportunity seeking and identification, financing new enterprises, corporate venturing and other related topics. Research subjects address the conceptualization of new venture business models through to formulating exit strategies. Special areas of emphasis include intellectual property commercialization, international and cross-cultural studies, and issues associated with transgenerational entrepreneurship in family business.

Information Technology concentration: Students will learn to use qualitative and quantitative methods to develop and apply theories regarding design, implementation, and use of advanced information systems and technologies with the goal of developing and publishing new Information Technology knowledge. Students will study information technology and how it affects individuals, organizations and society. By working closely with WPI's Information Technology scholars, students will learn to conduct theoretically sound Information Technology research that addresses real business problems, to apply for research grants, and to teach Information Technology courses. WPI's Information Technology scholars will involve Ph.D. candidates in their research activities in various organizations in the region, including those in the technology, healthcare, financial, and public sectors.

Operations Management concentration: Students will pursue research in the areas of management sciences, operations research, business analytics, health care management, supply chain management, and decision analysis. The operations area undertakes research on decision-making through quantitative modeling of operations functions in businesses. Research topics cover all levels of business decision-making, from operation systems design and technology choices to day-to-day scheduling and performance measurement. The program emphasizes research that focuses on real business problems and maintains a balance between theory and practice. This concentration is designed to train Ph.D. students in fundamental and applied business modeling and analytical thinking.

Academic Advising

Upon admission to the Doctoral Program, each student is assigned or may select a temporary advisor to arrange an academic Plan of Study covering the first 9 credits of study. This plan should be arranged before the first day of registration. Prior to registering for any additional credits, the student must identify a permanent dissertation advisor who assumes the role of academic advisor and with whom a suitable dissertation topic and the remaining Plan of Study are arranged. Prior to completing 18 credits, the student must form a dissertation committee that consists of the dissertation advisor, at least two other business administration faculty members, and at least one member from outside the student's area of concentration. These committee members should be selected because of their abilities to assist in the student's dissertation research.

The schedule of advising is as follows:

- Temporary advisor—meets with student prior to first registration to plan first 9 credits of study.

Return to Table of Contents

- Dissertation advisor—selected by student prior to registering for more than 9 credits.
- Program of study—arranged with dissertation advisor prior to registering for more than 9 credits.
- Dissertation committee—formed by student prior to registering for more than 18 credits. Consists of dissertation advisor, at least two B.A. faculty members, and at least one outside member.

This schedule ensures that students are well advised and actively engaged in their research at the early stages of their programs.

Admission to Candidacy

Admission to candidacy will be granted when the student has satisfactorily passed a written exam intended to measure fundamental ability in the area of concentration and at least one additional business discipline. The two areas are selected by the student. The exam is given in January. For students who enter the program with a bachelor's degree, the exam must be taken after three semesters if they began their studies in the fall, and after two semesters if they began in the spring. For students who enter the program with a master's degree, the exam must be taken after one semester if they began in the fall, and after two semesters if they began in the spring.

Students in a WPI M.S. program who plan to apply for fall admission to the Ph.D. program are strongly advised to take the candidacy exam in January before that fall. The details of the examination procedure can be obtained from the School of Business Research Policy and Curriculum Committee.

Dissertation Proposal

Each student must prepare a brief written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to date. The proposal must be made within a year of admission to candidacy. Both the written and oral proposals are presented to the dissertation committee and a representative from the School of Business Research Policy and Curriculum Committee. The prepared portion of the oral presentation should not exceed 30 minutes, and up to 90 minutes should be allowed for discussion. If the dissertation committee and the graduate committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 45 minutes allowed for discussion. Students can continue their research only if the proposal is approved.

Dissertation Defense

Each doctoral candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the dissertation committee and a representative of the School of Business Research Policy and Curriculum Committee who is not on the dissertation committee. The defense is open to public participation and consists of a 45-minute presentation followed by a 45-minute open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the School of Business Research Policy and Curriculum Committee. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

Course Descriptions

All courses are 3 credits unless otherwise noted.

ACC 500. Accounting and Finance Fundamentals

(1 credit)

This course serves as a foundational introduction to financial accounting and financial analysis. It is designed to help students master the technical skills needed in a graduate management curriculum and in business to analyze financial statements and disclosures for use in financial analysis. Students will learn how to read and interpret the three most common financial statements: the income statement, balance sheet, and statement of cash flows. Students will also learn how to apply ratios that capture key elements of a firm's performance. Students will also develop an understanding of certain essential concepts in mathematical financial analysis, including net present value (NPV), internal rate of return (IRR), payback, future value, and bond and options pricing. (Students cannot get credit for ACC 500 and ACC 503)

ACC 502. Financial Intelligence and Strategic Decision-Making

(2 credits)

This course builds on students' knowledge of financial statements and takes a managerial accounting approach to present how firms plan and implement strategy. Accounting, economics, and psychology theories provide the framework for cost analysis, strategic decision-making, and planning under uncertainty. Management control systems will guide students to work with uncertainty. Fundamental quantitative techniques will enable students to perform descriptive and predictive analytical approaches and empower them to make data-driven decisions. The course will emphasize cost behaviors, setting and meeting cost targets, assessing strategic initiatives, forecasting and budgeting, and the use of assumptions in the calculations of significant revenue and expense projections. Students will apply theories and best practices through simulations and case analyses. (Prerequisite: ACC 500) (Students cannot get credit for ACC 502 and ACC 503)

ACC 505. Performance Measurement and Management

(1 credit)

This course strengthens students' understanding of strategic finance/Financial Information & Management in order to monitor and revise strategy. It takes a managerial accounting approach to enable managers to measure and manage firm financial and non-financial performance. Accounting, economics, and psychology theories provide the framework for understanding moral hazard, motivation, and aligning the interest of employees with the interest of the firm. The course will emphasize designing and applying management control systems tools such as the balanced scorecard and examine how choices of what to measure affect behaviors and outcomes. Students will apply theories and best practices through simulations and case analyses. (Prerequisites : ACC 500, ACC 502, FIN 503 & FIN 504)

BUS 500. Business Law, Ethics and Social Responsibility

This course combines analysis of the structure, function and development of the law most important to the conduct of business with an examination of the ethical and social context in which managers make decisions. Emphasizing the social responsibility considerations of all business stakeholders, the course focuses on practical applications via extensive use of case studies. Students will gain a sound understanding of the basic areas of U.S. and international law including: intellectual property law; business formation and organization; international business law; securities regulation; cyber law and e-commerce; antitrust law; employment law and environmental law.

Return to Table of Contents

BUS 522. Global Business Experience

Business is increasingly global. To be successful one must understand the customs and traditions of the regions in which they are operating. This course provides students with insight into different countries and business environments and includes an international trip where students will spend a week to 10 days on the ground in the featured region meeting with business, government and/or academic leaders; touring company sites; and learning about the region. Prior to the trip students will study business history, culture and current topics related to the featured region. Guest speakers will often be incorporated. Following the trip students will typically write reflective papers and deliver presentations.

BUS 545. Introduction to Health Systems

This course introduces students to the structure of health systems (suppliers, providers, and payers), exploring processes, structure, and infrastructure elements. Topics include an overview of care models and processes, health information technologies, privacy and other regulations, and payment mechanisms. The course also explores future visions of health systems, focused around wellness, patient-centeredness, and value, supported by new technologies and care models.

BUS 546. Managing Technological Innovation

This course studies successful innovations and how firms must enhance their ability to develop and introduce new products and processes. The course will discuss a practical model of the dynamics of industrial innovation. Cases and examples will be discussed for products in which cost and product performance are commanding factors. The important interface among R&D/ manufacturing/marketing is discussed. International technology transfer and joint venture issues are also considered.

BUS 547. Energy Management

This course covers a broad spectrum of energy auditing methods, energy management planning and energy management topics important to future energy professionals, business managers and leaders. The course includes a project that applies energy management concepts to an actual energy audit. The audit project also includes the development of an energy management plan for a selected building making cost-effective recommendations to improve efficiency. Additional topics include: energy management strategies for business, governmental regulations, incentives and resources, European Union energy policies and programs including carbon credits and related markets. Energy efficiency practices as they relate to ISO 50001 Energy Management Systems, the U.S. Green Building Council (USGBC), and Leadership in Energy & Environmental Design (LEED), high performance buildings, data centers, renewable energy sources and smart grid are also studied. Special focus will be on energy management for financial and environmental sustainability benefits from the perspective of CEOs, CFOs, COOs and CSOs.

BUS 590. Strategy in Technology-based Organizations

This course provides a summary overview of strategic management, with a focus on integrating the core curriculum to develop competitive advantage at the corporate and business unit level. Topics include the role of the CEO in the organization, industry analysis, the use of core competence to drive business development and exit decisions, causes of organizational inertia that cause the loss of competitive advantage, the impact of technology on strategy, the links between strategy and organizational design, and the social responsibility of the firm. The course also serves as the initial phase of BUS 599 (Capstone) and is designed to be taken immediately preceding that class. (Prerequisites: ACC 500, ACC 502, ACC 505, BUS 500, FIN 503, FIN 504, MIS 500, MKT 500, OBC 505, OBC 506 and OIE 501 or equivalent content, or instructor consent) (Students cannot get credit for BUS 590 and BUS 501)

BUS 595. The Edge of Technology in STEM Industries

The course explores the state of technology and important technology trends in key industries. Students will conduct in-depth investigation of key issues and decisions faced by technology-intensive organizations in various sectors including health care, medical devices, biotech, IT hardware and software, FinTech, manufacturing and defense. Deans of Arts & Sciences, Business and Engineering as well as high profile guest speakers from industry will be involved in teaching the course.

BUS 596. Master of Science Capstone Project

This course is the capstone course for the STEM-based, specialty MS programs in the Foisie School of Business. This course serves as a practical integration of the STEM-based tools, techniques, and skills and the related business theories and practices that students learned in their MS program. The medium is a major team-based project in the form of an actual corporate STEM-based business need for which students will develop solutions. Students will produce a written report that documents and provides the financial, organizational, and technical rationale for the solutions. They will also formally present their results to the project sponsors. Students are expected to have completed (or are currently completing) all the courses requirements for their MS program prior to taking the capstone project. While the capstone requirements are the same for all STEM-based, specialty MS programs in the Foisie School of Business, the actual content of the project will differ by sponsor and by MS program. Students must take the appropriate section of BUS 596 for each MS program they complete.

BUS 598. Independent Study

The student should have a well-developed proposal before approaching a faculty member about an independent study.

BUS 599. Capstone Project

This capstone course integrates management theory and practice, and incorporates a number of skills and tools acquired in the M.B.A. curriculum. The medium is a major team-based project in the form of a corporate venture or green field venture. In addition to a written report, the project is formally presented to a panel of outside experts including serial entrepreneurs and investors. (Prerequisites: ACC 500, ACC 502, ACC 505, BUS 500, BUS 590, FIN 503, FIN 504, MIS 500, MKT 500, OBC 505, OBC 506 and OIE 501 or equivalent content, or instructor consent) (Students cannot get credit for BUS 599 and BUS 517)

BUS 5900. Internship

The internship is an elective-credit option designed to provide an opportunity to put into practice the principles that have been studied in previous courses. Internships will be tailored to the specific interests of the student. Each internship must be carried out in cooperation with a sponsoring organization, generally from off campus, and must be approved and advised by a WPI faculty member in the School of Business. Internships may be proposed by the student or by an off-campus sponsor. The internship must include proposal, design and documentation phases. Following the internship, the student will report on his or her internship activities in a mode outlined by the supervising faculty member. Students are limited to counting a maximum of 3 internship credits toward their degree requirements. Students must be making satisfactory academic progress as defined in the WPI graduate catalogue to be eligible to register for internship credit. International students who are working on a second U.S. master's degree and who have already used their master's-level Optional Practical Training (OPT) may petition the School of Business' Graduate Policy and Curriculum Committee to do additional Curricular Practical Training (CPT) beyond 3 credits on a non-credit basis. Part-time students cannot do an internship at their place of employment.

BUS 691. Graduate Seminar

(0 credits)

Seminars on current issues related to entrepreneurship, information technology and operations management are presented by authorities in their fields. All full-time Ph.D. students in Business Administration are required to register and attend.

BUS 697. Independent Study

(1-3 credits)

For Ph.D. students wishing to conduct independent study on special topics related to their concentration. (Prerequisite: Consent of research advisor)

BUS 698. Directed Research

(Credits TBD)

For Ph.D. students wishing to gain research experience peripheral to their thesis topic. (Prerequisite: Consent of research advisor)

Return to Table of Contents

BUS 699. Dissertation Research

(Credits TBD)

Intended for Ph.D. students admitted to candidacy wishing to obtain research credit toward their dissertations. (Prerequisite: Consent of research advisor)

BUS 6900. Internship for Ph.D. Students

ETR 500. Entrepreneurship and Innovation

Entrepreneurship involves many activities, including identifying and exploiting opportunities, creating and launching new ventures, introducing new products and new services to new markets. It is based on implementing innovations within existing organizations and creating new opportunities. This course is intended to introduce students to entrepreneurial thinking and methods of executing their ideas. Topics include recognizing and evaluating opportunities, forming new venture teams, preparing business and technology commercialization plans, obtaining resources, identifying execution action scenarios, and developing exit strategies.

ETR 593. Technology Commercialization: Theory, Strategy and Practice

In the modern world of global competition the ability to utilize technological innovation is increasingly important. This course will examine the sources of new technology, the tools to evaluate new technologies, the process of intellectual property transfer, and the eventual positioning of the resultant products and services in the commercial market. Its purpose is to improve the probability of success of this discipline in both existing organizational models and early stage ventures. Specific cases studies of successful technology commercialization processes will be used to supplement the course materials.

ETR 596. Selling and Sales

Selling is a major part of our business and professional lives. This is especially important for those who are launching new ventures. Business propositions need to be presented to (and need to be sold to) potential investors, employees, colleagues, and certainly potential employers. Later there is a need to sell products or services to customers. Common to all is a sales process and organization model that can be developed that is focused on meeting customer and other stakeholder needs through effective selling disciplines.

FIN 500. Financial Information and Management

This course develops expertise in financial decision-making by focusing on frequently used financial accounting information and the conceptual framework for managing financial problems. Students are introduced to the accounting and financial concepts, principles and methods for preparing, analyzing and evaluating financial information, for the purpose of managing financial resources of a business enterprise and investment decisions. The course adopts a decision-maker perspective by emphasizing the relations among financial data, their underlying economic events, and corporate finance issues. The course provides an overview of the financial reporting system, to enable data analysts in building queries for financial analyses and in forecasting possible future financial scenarios.

FIN 503. Financial Decision-Making for Value Creation

This course develops and enhances the student's ability to implement and clearly communicate a firm's financial decisions related to value creation. The course covers capital structure optimization, cost of capital; capital allocation and investment strategies, enterprise risk, project and firm valuation, and international financial management. The course adopts a decision-maker's perspective by emphasizing the relationships among a firm's strategic objectives, financial accounting and financial statement data, economic events, responses by market participants and other impacted constituencies, and corporate finance theory. The course also builds on these practical finance skills by incorporating team-based assignments, real-world simulations, and a variety of financial modeling tools. (Students cannot get credit for FIN 503 and FIN 500)

FIN 504. Financial Statement Analysis and Valuation

(2 credits)

This course develops expertise in financial decision-making by focusing on financial accounting information. The course presents a comprehensive framework for financial statement analysis and valuation. Through hands-on, practical application of various tools for financial analysis (e.g., ratio analysis & financial modeling using Excel and other resources) students will develop the expertise needed to use a firms' financial statements to draw an understanding of its performance and to provide a basis for making reasonable valuation estimates. Students will learn to apply analytical techniques to develop forecasted financial statements and use the information to value a firm's equity. The course will utilize team assignments, cases, simulations, and other applied exercises. (Prerequisites: ACC 500, ACC 502, & FIN 503)

FIN 521. Financial Management in a Global Environment

This course builds from Financial Information and Management, and extends closed-economy financial management to the international market environment. Drawing from theories based on culture, corporate finance, and investor protection laws, this course examines differences in corporate governance, financial information, and financial markets in global settings. The first focus is on accountability of financial resources, the implications of globalization on firms' financial reporting and decision-making. The second focus is on international markets and institutions, how the access and exposure to different market environments can affect the firm's financial and investment decisions. Major topics include the relationship between foreign exchange and other financial variables; measurement and management of the exchange risk exposure of the firm; international investment decisions by firms and investors; and financing the global operations of firms. (Prerequisite: FIN 500 or equivalent content, or consent of instructor)

FIN 522. Financial Institutions, Markets & Technology

This course will examine financial institutions and the relationship between U.S. capital markets and global markets. The class is intended to help students understand the impact of financial intermediaries on the global economy, businesses, and consumers. The course will investigate the organization, structure, and performance of money and capital markets and institutions. The class will examine the major financial management issues confronting financial service firms (depository institutions, insurance companies, investment banks, mutual funds, hedge funds, and pension funds), and it will address the legal, regulatory, financial reform, and risk management issues facing these financial institutions and markets. Finally, the course will address the rapid evolution of the financial sector as a result of technology. We will consider how financial technology ("FinTech") is being developed by startup technology firms and existing financial institutions may disrupt the financial sector through innovation in digital and electronic currencies, online finance and investment platforms, big data, and digital payment systems among other topics.

FIN 598. Special Topics

MIS 500. Innovating with Information Systems

This course focuses on information technology and innovation. Topics covered are information technology and organizations, information technology and individuals (privacy, ethics, job security, job changes), information technology and information security, information technology within the organization (technology introduction, and implementation, and data analytics for competitive analysis), business process engineering and information technology between organizations (electronic data interchange and electronic commerce). This course provides the knowledge and skills to utilize existing and emerging information technology innovatively to create business opportunities.

MIS 502. Data Management for Analytics

This course develops the skills business students need for handling data. It focuses on student skills in (1) cleaning and preparing data for analysis, (2) writing SQL queries to access and manipulate data, and (3) ethical uses of data and data privacy issues. It also covers the types of data typically found in organizations, e.g., employee, customer, product, marketing, operations, and financial data.

MIS 571. Database Applications Design and Development

This course introduces students to the theory and practice of computer-based data management, including the delivery of high quality data in information processing and analysis. The course focuses on the design of database systems to meet an organization's needs for data analytics. The course also covers data security, data integrity, data quality, as well as backup and recovery procedures. Students will be exposed to commercially available database management systems, such as Microsoft Access and Oracle. As a project during the course, students will design and implement a small database application that meets the data needs of some real-world business opportunity. The project report will include recommendations for ensuring data security, data integrity, and data quality.

MIS 573. System Design and Development

This course introduces students to the concepts and principles of systems analysis and design. It covers all aspects of the systems development life cycle from project identification through project planning and management, requirements identification and specification, process and data modeling, system architecture and security, interface design, and implementation and change management. Object-oriented analysis techniques are introduced. Students will learn to use an upper level CASE (computer-aided software engineering) tool, which will be employed in completing a real-world systems analysis and design project. (Prerequisite: MIS 571 or equivalent content, or instructor consent)

MIS 576. Project Management

This course presents the specific concepts, techniques and tools for managing projects effectively. The role of the project manager as team leader is examined, together with important techniques for controlling cost, schedules and performance parameters. Lectures, case studies and projects are combined to develop skills needed by project managers in today's environment.

MIS 581. Policy and Strategy for Information Technology and Analytics

This course focuses on the core IS capabilities that IS managers must consider when managing technology within an organization, such as IT strategy, policy development, management, and IT's role in data analytics. Fast-paced changes in technology require IT managers to quickly understand, adapt, and apply technology. Successful companies are those that can react quickly by introducing innovative technologies and respond to market demands using data driven solutions. Students will learn how IT managers engage data to develop and enhance their departments' strategies.

MIS 582. Information Security Management

This course introduces students to the fundamentals of Information Security Management. It is designed to develop in students an understanding of and appreciation for the importance of information security to all enterprises, and to enable current and future managers to understand the important role that they must play in securing the enterprise. This course is appropriate for any student interested in gaining a managerial-level understanding of information security. A combination of readings, lectures, case studies, guest speakers, and discussion of real world events will be used to bridge the gap between theory and practice. The course will primarily explore the Common Body of Knowledge (CBK) of information security, along with other related topics. It will also explore the interaction between People, Process and Technology as the cornerstone of any effective information security program. Upon completion of this course, the student will have an in-depth understanding of the essential components of a comprehensive information security program, as well as an understanding of the technology at work behind the scenes.

MIS 583. User Experience Applications

The UX Applications course provides an introduction to using UX methods to study user experience. The course teaches students how to use the newest research tools, including eye tracking and emotion detection, to study user experiences of technological products and services. Students will learn how businesses can benefit from these techniques. Both theoretical concepts and practical skills will be addressed within the scope of the class through hands-on projects, class exercises, and assignments.

MIS 584. Business Intelligence

Today's business computing infrastructures are producing the large volumes of data organizations need to make better plans and decisions. This course provides an introduction to the processes, technologies, and techniques for organizing, analyzing, visualizing, and interpreting data and information about business operations in a way that creates business value. During the course, students will study a variety of business decisions that can be improved by analyzing data about customers, sales, and operations, preparing students to be knowledgeable producers and consumers of business intelligence. Students will apply commercially available business intelligence software to develop performance dashboards to facilitate organizational decision-making. The course explores the technical challenges of organizing, analyzing, and presenting data and the managerial challenges of creating and deploying business intelligence expertise in organizations. The course includes business cases, in-class discussion, and hands-on analyses of business data. It is designed for any student interested in learning about data-driven business performance management and decision-making, including students whose primary focus is Data Science, IT, Marketing, Operations, or Business Management.

MIS 585. User Experience Design

Designing positive user experiences is becoming increasingly important in staying competitive in the marketplace. This UX Design course offers students hands-on experiences, through the use of real-world projects, that provide them with a strong portfolio of work that showcases their skills in UX/UI, visual, service, experience, and product design. Throughout this course, students will create innovative experiences that enrich their technical fluency in both web and interactive development. The course provides a foundation in art and design in order to help students articulate their work to stakeholders and translate outcomes as business value.

MIS 586. User Experience Research Methods

In today's digital economy, understanding how people use and experience technology is crucial to designing successful technological products and services. This course covers the methodologies and tools for conducting research in the User Experience (UX) field. The course covers both qualitative and quantitative methods for conducting UX research in academia and industry, including surveys, persona development, customer journey maps, and other industry-standard tools for studying user experience. Both cutting-edge theoretical concepts and proven practical skills will be addressed within the scope of the class through hands-on projects, class exercises, and assignments.

MIS 587. Business Applications in Machine Learning

This course explores how Machine Learning (ML) and Artificial Intelligence (AI) is applied to solve business problems, to satisfy specific business needs, or to discover new opportunities for businesses. Applications of ML and AI are constantly evolving across many industries. This course utilizes existing AutoML solutions to address issues identified in business case studies (e.g. predicting hospital readmissions, loans likely to default, customer churn). The course covers the machine learning project life cycle starting with defining ML project objectives, acquiring and exploring data, modeling using AutoML tools, interpretation of models and communication of outcomes, and implementation and deployment of predictive models in organizations.

MKT 500. Marketing Strategy

This course focuses on the development and marketing of products and services that meet customer needs. Topics covered include management and the development of distinctive competence, segmentation and target marketing, market research, competitor analysis and marketing information systems, product management, promotion, pricing strategy, and channel management. Students will learn how the elements of marketing strategy are combined in a marketing plan based on marketing analytics, and the challenges associated with managing products and services over the life cycle, including strategy modification and market exit.

Return to Table of Contents

MKT 561. Consumer Behavior and Analytics

We are living in a data-driven world. Everything we do from getting our news in the morning, to buying goods, and searching for information leaves trails of data across the Internet. Consumers have changed and companies need to find new ways to engage with consumers in order to stay profitable and relevant. As a working professional, you will be tasked to use data to make business decisions and develop strategy that create value for consumers and your organization. This course will introduce traditional theories of consumer behavior and then take you on a beginning journey through the dynamic practices of how to use consumer data and analytics in the digital age. Topics covered include consumer behavior theory, an examination of attitude formation and value creation, the challenges of consumer protection, market research, and the influence of technology on consumer decision making.

MKT 562. Marketing Research

This course is designed to equip students with research methods and tools that are used for marketing decision making. Students will learn to conduct, use, apply, interpret, and present marketing research in order to become effective decision makers. The topics covered in this course include problem formulation, research design, data collection methods, data analysis, and finally presentation of a research plan. This course will be an activity-based course involving design, implementation, and presentation of a marketing research plan. Basic knowledge of marketing and statistical concepts is assumed.

MKT 564. Global Technology Marketing

Extending technology to global markets requires an understanding of consumer behavior in different cultures, and effective management of risk and overseas infrastructures. This course addresses the issues associated with technology application in new markets and includes the following topics: consumer behavior differences in international markets and the implications for the marketing mix, cultural differences that affect business practices in new markets, managing exchange rate fluctuation, factors that affect manufacturing and research location, the impact of local government on marketing decision making, and the use of strategic alliances to acquire expertise and manage risk in global market development. Knowledge of marketing management is assumed.

MKT 565. Digital Marketing

The rapid evolution of technology has led to increasingly well-informed buyers who are connected, communicative, and more in control than ever. This course discusses the theory and practice of digital marketing and its role in building relationships and, ultimately, driving sales. It examines digital technologies and their impact on business models, the marketing mix, branding, communication strategies, and distribution channels. Emphasis is placed on contemporary topics that face today's marketing managers – including online lead generation, search, social networking, and ecommerce – and their application within a comprehensive, integrated digital marketing strategy. The course considers the opportunities and challenges faced in business-to-consumer and business-to-business markets. It covers latest research, current practices, and hands-on project work.

MKT 567. Integrated Marketing Communications

This course provides students with an understanding of the role of integrated marketing communications in the overall marketing program and its contribution to marketing strategy. The tools of marketing communications include advertising, sales promotion, publicity, personal selling, public relations, trade shows, direct, and online marketing. Understanding the concepts and processes that organizations use in developing effective and synergistic marketing communications is useful for managers across functional disciplines. This course will also consider ethical issues of IMC.

MKT 568. Data Mining Business Applications

This course provides students with the key concepts and tools to turn raw data into useful business intelligence. A broad spectrum of business situations will be considered for which the tools of classical statistics and modern data mining have proven their usefulness. Problems considered will include such standard marketing research activities as customer segmentation and customer preference as well as more recent issues in credit scoring, churn management and fraud detection. Roughly half the class time will be devoted to discussions on business situations, data mining techniques, their application and their usage. The remaining time will comprise an applications laboratory in which these concepts and techniques are used and interpreted to solve realistic business problems. Some knowledge of basic marketing principles and basic data analysis is assumed.

MKT 569. Product and Brand Management

The conversion of technology into new products requires an understanding of how to develop a meaningful value proposition and integrate the development of a product with a marketing strategy that creates brand equity. This course will focus on the management of products, the implications of other marketing decisions on product and brand management, the management of product lines within the organization, including introduction, growth, and market exit. (Prerequisite: MKT 500 or equivalent content, or consent of instructor.)

MKT 598. Special Topics

OBC 505. Teaming and Organizing for Innovation

How do we navigate complex human systems in organizations? How do we foster innovation within organizations? In this course, we explore the paradoxes, opportunities, and hidden systemic challenges that arise on teams and projects, and in working across networks and within innovative organizations. Students will learn to more deftly manage the inherent challenges and opportunities of cross-cultural and multi-disciplinary teams; work through or avoid dysfunctional team and organizational conflicts; wrestle with ambiguity and uncertainty; negotiate change by learning to work with networks of power and influence; and analyze the individual, group, organizational and contextual dynamics that enable and constrain productive and innovative work in organizations. (Students cannot get credit for OBC 505 and OBC 500)

OBC 506. The Heart of Leadership: Power, Reflection, and Interpersonal Skills

All of us hope to have positive, collaborative, and effective interactions with others — in our professional and personal lives. Yet often our interactions do not go as planned and it gets ugly: people behave irrationally and get emotional, communication stops, conflicts fester, and opportunities are left unrealized and obscured. This course develops skills for understanding and acting more powerfully, ethically, and mindfully in our interactions. These include analytic techniques for understanding emotional, biographical, and social-psychological reasons for our own and others behavior, and skills for paying attention to and managing the complex dynamics unfolding in interpersonal interactions. Students will learn to identify and reflect upon their own contributions to problematic interactions; design and execute better ways of interacting with others; and develop their own interpersonal strengths and collaborative capacities. (Prerequisite: OBC 505 or instructor consent) (Students cannot get credit for OBC 506 and OBC 501)

OBC 533. Negotiations

This course focuses on improving the student¹s understanding of the negotiation process and effectiveness as a negotiator. Emphasizes issues related to negotiating within and on behalf of organizations, the role of third parties, the sources of power within negotiation, and the impact of gender, culture and other differences. Conducted in workshop format, combining theory and practice.

OBC 535. Managing Creativity in Knowledge Intensive Organizations

This course considers creativity in its broadest sense from designing new products and processes to creating our own role and identity as managers and leaders in knowledge-intensive organizations. In this course we will look actively at our own creative process and how we might more fully realize our creative potential. At the same time we will build a conceptual understanding of creating, creativity, and knowledge based in the philosophic, academic, and practitioner literatures. We will critically apply this conceptual understanding to organizational examples of managing creativity in support of practical action.

Return to Table of Contents

OBC 536. Organizational Design
A key role for organizational leaders is to design their organization to achieve their desired results. This course applies design thinking and methods to the practical problems of designing various sized organizations for optimal results in a complex environment. This is based on a foundation of organizational theory, design methodology, and organizational strategy. (Prerequisite: OBC 505 or equivalent content, or instructor consent)

OBC 537. Leading Change
This course focuses on the role of leadership in the design and implementation of organizational change. Topics include visioning, communication, social influence, power, resiliency, and resistance to change. Teaching methods include classroom discussion of readings and cases, simulations, and experiential exercises. (Prerequisite: OBC 505 or equivalent content, or instructor consent)

OBC 538. Developing Managerial Talent
Assessing and developing managerial talent in yourself and others is a key to professional success and can be a source of organizational competitive advantage. This course addresses the Globalizing World and You, and provides students access to the frameworks, tools, and practice necessary to engage in thoughtful self-assessment, constructive feedback acquisition and interpretation, and strategic development planning for themselves as well as for others on their teams and in their organizations. The goals of this course are: a) to help students assess their own managerial abilities, b) to develop plans for securing new knowledge, skills and abilities that will help them in their careers, c) to set goals and agendas for their own development and d) to consider ways to translate this development process to others.

OIE 501. Designing Operations for Competitive Advantage
The operations function in an organization is focused on the transformation processes used to produce goods or provide services. Operations design is driven by strategic values, and innovative improvements can support sustained competitive advantage. In this course, a variety of analytical and statistical techniques are introduced to develop a deep understanding of process behavior, and to use this analysis to inform process and operational designs. Topics such as process analysis and value stream mapping, postponement and global and local supply chain strategies, queuing models, and managing system constraints are covered using case studies and hands-on activities such as online simulations. Non-traditional operations systems are also explored. The skills required to model an operational system, to reduce variation and mitigate bottlenecks, to effectively present resource needs, and to adjust capacity and inventory service levels are practiced during the course. (Students cannot get credit for OIE 501 and OIE 500)

OIE 542. Risk Management and Decision Analysis
Risk management deals with decision making under uncertainty. It is interdisciplinary, drawing upon management science and managerial decision-making, along with material from negotiation and cognitive psychology. Classic methods from decision analysis are first covered and then applied, from the perspective of business process improvement, to a broad set of applications in operations risk management and design including: quality assurance, supply chains, information security, fire protection engineering, environmental management, projects and new products. A course project is required (and chosen by the student according to his/her interest) to develop skills in integrating subjective and objective information in modeling and evaluating risk. (Prerequisite: OIE 501 or equivalent content, or instructor consent.) (Students cannot get credit for both OIE 542 and OIE 541.)

OIE 544. Supply Chain Analysis and Design
This course studies the decisions, strategies and analytical methods in designing, analyzing, evaluating, and managing supply chains. Concepts, techniques, and frameworks for better supply chain performance are discussed, and how digital technologies enable companies to be more efficient and flexible in their internal and external operations are explored. The major content of the course is divided into three modules: supply chain integration, supply chain decisions, and supply chain management and control tools. Students will learn how to apply some of the techniques in Operations Research such as linear programming, dynamic programming, and decision tree to aid decision-making. A variety of instructional tools including lectures, case discussions, guest speakers, games, videos, and group projects and presentations are employed. (Prerequisite: OIE 501 or equivalent content, or instructor consent)

OIE 548. Performance Analytics
Productivity management and performance analysis techniques and applications are covered from engineering and management perspectives. Topics include benchmarking, production functions, and the concept of relative efficiency and its measurement by data envelopment analysis. Application examples include efficiency evaluations of bank branches, sales outlets, hospitals, schools and others.

OIE 552. Modeling and Optimizing Processes
This course is designed to provide students with a variety of quantitative tools and techniques useful in modeling, evaluating and optimizing operation processes. Students are oriented toward the creation and use of spreadsheet models to support decision-making in industry and business.

OIE 553. Global Purchasing and Logistics
This course aims to develop an in-depth understanding of the decisions and challenges related to the design and implementation of a firm's purchasing strategy within a context of an integrated, global supply chain. Topics centering on operational purchasing, strategic sourcing, and strategic cost management will be covered. The global logistics systems that support the purchasing process will be analyzed, and the commonly used techniques for designing and evaluating an effective logistics network will be studied.

OIE 554. Global Operations Strategy
This course focuses on operations strategy from a global perspective. Topics such as strategy of logistics and decisions to outsource are examined. As an example, the strategic issues concerned with firms that are doing R&D in the United States, circuit board assembly in Ireland and final assembly in Singapore. Cases, textbooks and recent articles relating to the topic are all used. Term paper based on actual cases is required. (Prerequisite: OIE 501 or equivalent content, or instructor consent)

OIE 556. Health Systems Modeling and Improvement
This course is organized around problem-solving frameworks for designing and improving health systems, exploring specific methodologies and their role in organizational change. Tools and techniques from operations management, industrial engineering, statistics, and management sciences, are used to explore common health systems design and management issues, focusing on data requirements and decision-making. Issues that may be explored include demand forecasting, process design, product design, and staffing and scheduling.

Return to Table of Contents

OIE 557. Service Operations Management

Successful management of service organizations often differs from that of manufacturing organizations. Service business efficiency is sometimes difficult to evaluate because it is often hard to determine the efficient amount of resources required to produce service outputs. This course introduces students to the available techniques used to evaluate operating efficiency and effectiveness in the service sector. The course covers key service business principles. Students gain an understanding of how to successfully manage service operations through a series of case studies on various service industries and covering applications in yield management, inventory control, waiting time management, project management, site selection, performance evaluation and scoring systems. The course assumes some familiarity with basic probability and statistics through regression.

OIE 558. Designing and Managing Lean Six Sigma Processes

In this course, Lean Six Sigma is presented as an organizational improvement system and a set of process analysis and statistical tools that have helped the world's leading organizations achieve operational excellence, saving millions of dollars and improving customer satisfaction. This course is organized in three parts: part one covers the essentials of Lean Six Sigma, including fundamental concepts and problem-solving methods; part two of the course covers Lean Six Sigma tools, including topics such as value-stream mapping, process capability, and experimental design; part three describes the major activities in a Lean Six Sigma roadmap, from identifying core processes to executing improvement projects to sustaining Lean Six Sigma gains.

OIE 559. Optimization for Business Analytics

This course covers mathematical optimization beyond the foundational concepts of linear programming. Approaching from the perspective of obtaining globally optimal solutions, a variety of optimization problem classes will be addressed, likely including integer programming, nonlinear programming, and stochastic programming. While ensuring an appropriate level of theory, the emphasis of the course will be on the mathematical modeling and computational solution aspects of such problems that may arise in the finance, healthcare, humanitarian, inventory, nonprofit, operations, production, staffing, and supply chain sectors, among others. (Prerequisite: OIE 552, equivalent knowledge about optimization and linear programming, or consent of the instructor).

OIE 598. Special Topics

OIE 599. Supply Chain Research

This research study is at the master's level. The course provides a research experience for students interested in studying a pressing supply chain management problem or challenge. Students must satisfactorily complete a written paper and are encouraged to publically present the results.

Chemical Engineering

Faculty

S. C. Roberts, Professor and Department Head; Ph.D., Cornell University. Cellular engineering, plant cell culture, biotechnology, metabolic pathway engineering

T. A. Camesano, Professor; Ph.D., Pennsylvania State University. Bacterial adhesion and interaction forces, biopolymers, bacterial/natural organic matter interactions

N. A. Deskins, Associate Professor; Ph.D., Purdue University. Energy production, nanomaterials research and development, pollution control and abatement, catalysis and chemical kinetics, and computational chemistry

D. DiBiasio, Professor; Ph.D., Purdue University. Engineering education, teaching and learning, assessment

A. G. Dixon, Professor; Ph.D., University of Edinburgh. Transport in chemical reactors, applications of CFD to catalyst and reactor design, membrane separation and reactors

N. K. Kazantzis, Professor; Ph.D., University of Michigan. Techno-economic performance analysis, sustainable design and control of chemical processes, energy production and environmental systems, valuation methods for clean energy technology options in the presence of uncertainty, process safety and chemical risk analysis

S. J. Kmiotek, Professor of Practice, Ph.D., Worcester Polytechnic Institute. Chemical process safety, air pollution control, pollution prevention

E. J. Stewart, Assistant Professor, Ph.D., University of Michigan. Biological soft matter, bacterial biofilms, biophysics of host-pathogen interactions, complex fluids, microfluidics.

A. R. Teixeira, Assistant Professor; Ph.D., University of Massachusetts Amherst. Reaction engineering, heterogeneous catalysis, microfluidic crystallization

M. T. Timko, Associate Professor, Ph.D., MIT. Renewable energy, liquid and biomass fuels, reaction engineering, fuel refining and desulfurization

E. M. Young, Assistant Professor; Ph.D., University of Texas at Austin. Synthetic biology, metabolic pathway engineering, yeast gene expression, transport protein engineering

H. S. Zhou, Associate Professor; Ph.D., University of California-Irvine. Bionanotechnology, bioseparations, micro- and nano-bioelectronics, bioMEMS, microfluidics, polymer thin films, surface modification, microelectronic and photonic packaging

W. P. Zurawsky, Associate Teaching Professor; Ph.D., University of Illinois. Membrane permeation and separations, plasma processing.

Emeritus

W. M. Clark, Professor Emeritus; Ph.D., Rice University

R. Datta, Professor Emeritus; Ph.D., University of California, Santa Barbara

Y. H. Ma, Professor Emeritus; Ph.D., Massachusetts Institute of Technology

W. R. Moser, Professor Emeritus; Ph.D., Massachusetts Institute of Technology

R. W. Thompson, Professor Emeritus; Ph.D., Iowa State University

A. H. Weiss, Professor Emeritus; Ph.D., University of Pennsylvania

Research Interests

The Chemical Engineering Department's research efforts are concentrated in the following major areas: bioengineering and biomanufacturing, materials and soft matter, energy and the environment and computational science and engineering.

Bioengineering research focuses on cellular engineering, metabolic engineering, synthetic biology bio-materials, and cell-surface interactions. Materials and soft matter research focuses on biopolymers, advanced carbon materials, biointerfaces and nano-sensors. Energy and the environment research focuses on carbon capture, biomass conversion, resource and energy efficiency, catalysis, fuel cells, reaction engineering, solar energy and zeolite synthesis. Computational science and engineering research focuses on computational fluid dynamics, genome scale modeling, molecular modeling, process systems analyses and reactor design.

Master's and doctoral candidates' research in each of these areas involves the application of fundamental aspects of chemical engineering to interdisciplinary, societally relevant problems. Studies may be pursued in the following areas:

Bacterial Adhesion to Biomaterials

The mechanisms governing bacterial adhesion to biomaterials, including catheters and other implanted devices, are poorly understood; however, it is known that the presence of a biofilm on a biomaterial surface will lead to infection and cause an implanted device to fail. Research is aimed at characterizing bacterial interaction forces and adhesion to biomaterials, and developing anti-bacterial coatings for biomaterials. We are using novel techniques based on atomic force microscopy (AFM) to quantify the nanoscale adhesion forces between bacteria and surfaces.

Catalyst and Reaction Engineering

Research in this area is centered on the physical and chemical behavior of fluids, especially gases, in contact with homogeneous and heterogeneous catalysts as well as ways to improve organic and inorganic crystal growth. Projects include diffusion through porous solids, multicomponent adsorption, mechanism studies, microkinetics, reaction networks, synthesis and characterization of catalysts, catalytic reformers, electrochemical synthesis, heat and mass transfer in catalytic reactors, and simulation of catalyst surfaces and reaction sites. Experimental techniques include standard lab-scale reactors, microreactors, and in situ spectroscopic instruments to monitor chemical reactions. Applications include partial oxidation reactions, steam reforming to produce hydrogen, pharmaceuticals synthesis and conversion of bio-renewable feeds into commodity chemicals.

Return to Table of Contents

Fuel Cell and Battery Technology

Fuel cells have potential as clean and efficient power sources for automobiles and stationary applications. Research is being conducted on developing, characterizing and modeling of fuel cells that are robust for these consumer applications and includes development of CO-tolerant anodes, higher temperature proton-exchange membranes and direct methanol fuel cells. Ongoing research also includes reformers and membranes for production of hydrogen from liquid fuels, flow batteries for grid energy storage and fuel cells for electrochemical synthesis and reforming processes.

Soft Matter and Biointerfaces

Studies on the structure-property-function relationships within biological soft matter systems allow for advancements in the understanding of disease states as well as the development of biophysical strategies to combat disease. Our program's approach considers the physical interactions between cells, surfaces, biopolymers and their microenvironments to resolve cellular behaviors and design strategies for controlling cell growth. Our work is multidisciplinary and utilizes tools from engineering, the physical sciences, and biology. Research activities in the department are particularly focused on bacterial infection prevention and control with research thrusts in bacterial surface adhesion, mechanisms of antimicrobial peptide cytotoxicity, bacterial biofilm formation and dispersion, and in vitro models of host-pathogen interactions.

Lab-on-chip and BioMEMS

Research in the area of lab-on-chip and BioMEMS involves developing a fundamental understanding of microfluidics transport and surface reaction kinetics in the micro-and nano-domains to design and fabricate chip-based bioseparation and biosensing devices and application of bionanotechnology for rapid and sensitive molecular diagnostics. Novel nanomaterials for biomedical applications are also of interest.

Metabolic and Cellular Engineering

The goal of this research is to engineer advanced "cell factories". To accomplish this goal, researchers look to control gene expression, metabolism and protein function by writing new DNA sequences into genomes. Whether to understand fundamental questions about genetics, or to modify cells to produce valuable medicines and fuels, engineering DNA is an interdisciplinary challenge. Techniques such as next-generation sequencing, modeling, molecular biology and flow cytometry are used.

Molecular Modeling of Materials for Sustainability

Computer technologies have advanced to the point of being able to accurately determine properties of material and chemical systems. For example, catalysts involve a number of reactions that are difficult to determine using experimental techniques. Research is being conducted in the areas of photocatalysis, photovoltaics, industrial catalysis, and environmental catalysis, all with the goal of producing environmentally-safe energy and chemicals. Sample projects include determining active catalysts for CO2 photo-reduction to solar fuels, simulating alloys for fuel cells, and modeling carbon-based materials.

Plant Cell Biotechnology

Plant cells synthesize an array of sophisticated "specialized metabolites" that serve a variety of functions as human health agents, colors, flavoring and agricultural chemicals. Production of these compounds for clinical or industrial supply can be challenging due to their low yields in nature, under-defined metabolic pathways and difficult gene transformation technologies. Plant cell culture technology can be exploited not only to synthesize these valuable compounds, but also to gain fundamental insights into regulation of plant cell metabolism so that systems can be effectively engineered. By considering all scales of cellular engineering – intra, inter and extra, cultures can be designed to produce yield yields of desirable molecules.

Reactor modeling and simulation

A better understanding of interactions between reactor transport processes and chemical reaction is needed to improve reactor efficiency, which contributes to sustainable engineering. Multiscale approaches are used to give new insight into the development of catalysts and reactors, such as computational fluid dynamics (CFD) and multiphysics methods, for example microkinetics and multicomponent diffusion models can be integrated into the CFD simulations of fixed bed reactors. Applications include partial oxidation reactions, and steam reforming for generation of hydrogen and synthesis gas, one route towards the generation of clean power. Other research includes study of membrane modules for recovery of high-purity hydrogen, membrane reactors for process intensification of hydrogen generation, and new catalytic materials such as ceramic foams.

Sustainable Fuels

Transportation and shipping rely on access to affordable and abundant supplies of liquid fuels. Research is being conducted to deliver these liquid fuels in more sustainable ways, for example, using green technologies, waste feeds, and renewable feeds. The primary research tools include catalysis science, reactor design, computational modeling, and metabolic engineering. Breaking down lignocellulosic bio-polymers is one of the main technical and economic barriers preventing affordable production of biomass-derived fuels. New techniques and technologies are being developed to understand and control the de-polymerization processes. Fermentation of the resulting simple sugars is an effective method to produce hydrocarbon fuels. Here, work is on-going to develop fermenter technologies that produce drop-in biofuels, such as butanol. With conventional oil reserves dwindling, environmentally responsible upgrading of heavy oils is becoming increasingly important. Research into green technologies which reduce the energy footprint of heavy oil upgrading are being studied. Waste plastics represent an energy dense feed that is currently under-utilized. Work is ongoing to convert waste plastics into high-value monomers and liquid fuels. Likewise, food wastes are a low-cost and energy dense feedstock being studied for potential production of liquid fuels. Lastly, many of these processes co-produce a solid char material which reduces the energy yield of the oil product. Studies are ongoing to valorize these char products as waste water treatment sorbents and in other applications.

Techno-economic performance analysis, sustainable design, control and safety of chemical processes and energy systems

Current research efforts lie in the broader areas of nonlinear process techno-economic performance analysis, sustainable design, control and safety. In particular, the following thematic areas may be identified in our current research efforts: (1) Techno-economic performance assessment and technology valuation methods in the presence of uncertainty; (2) synthesis of robust digital feedback regulators for nonlinear processes; (3) design of state estimators for digital process performance monitoring and fault detection/ diagnosis purposes; (4) chemical risk assessment and management with applications to process safety; (5) development of the appropriate software tools for the effective digital implementation of the above process analysis, control, performance monitoring and risk assessment schemes

Zeolite Science and Technology

Research in the area of zeolite science is driven by the need to establish an underlying understanding of the complex phenomena driving the synthesis and applications of molecular sieve zeolites. In particular, utilizing core reaction engineering techniques to elucidate the fundamental mechanisms of zeolite nucleation and crystal growth in hydrothermal systems is of interest. Uses of zeolites as liquid and gas phase adsorbents, and as catalysts, are being studied. Incorporation of zeolites into membranes for separations is being investigated due to zeolites' very regular pore dimensions on the molecular level.

Programs of Study

Students have the opportunity to do creative work on state-of-the-art research projects as a part of their graduate study in chemical engineering. The program offers excellent preparation for rewarding careers in research, industry or education. Selection of graduate courses and thesis project is made with the aid of a faculty advisor with whom the student works closely. All graduate students participate in a seminar during each term of residence.

The master's degree program in chemical engineering is concerned with the advanced topics of the field. There are three choices for students wishing to obtain advanced knowledge in chemical engineering and related fields: professional engineering option with concentration, thesis option and non-thesis option. All students must complete three of the four core courses offered in mathematics, thermodynamics, reaction engineering, and transport phenomena. In addition, they choose courses from a wide range of electives and available projects.

In the doctoral program, a broad knowledge of chemical engineering topics is required for success in the qualifying examination. Beyond this point, more intensive specialization is achieved in the student's field of research through coursework and thesis research.

Admission Requirements

An undergraduate degree in chemical engineering is preferred for master's and doctoral degree applicants. Those with related backgrounds (e.g., chemistry, biomedical engineering, physics) are also encouraged to apply. We work closely with each student on individual plans to assure they are appropriately prepared for the master's and doctoral curricula, including participation in a "boot camp" course.

Degree Requirements

For the M.S.

Professional Engineering Option with Concentration

A total of 30 credit hours is required. At least 24 course credit hours must be in chemical engineering including 6 credit hours of Graduate Qualifying Project (GQP), 9 credit hours chosen from the chemical engineering core curriculum, 9 credits of concentration courses, and 6 credits of chemical engineering electives. Students select a concentration in either Bioengineering or Advanced Process Engineering. Bioengineering prepares students for the biotech, pharma and medical device industries, while Advanced Process Engineering focuses on advanced topics in design, control and optimization that are applicable to a wide range of chemical processing. The credit distributions for the different concentrations are shown in Table 1.

The GQP provides a capstone experience in applying chemical engineering skills to real-world problems. GQP's are carried out in cooperation with an industrial partner and with the approval and oversight of a faculty member in Chemical Engineering.

Students must take one required three-credit concentration course plus 6 credits chosen from a list of approved concentration courses. Students in the Bioengineering concentration must take CHE 521: Biochemical Engineering, while students in the Advanced Process Engineering concentration must take CHE 565: Advanced Process Engineering. There is flexibility in other concentration course choices so that students can further tailor their studies to their interests and needs. Courses for each of the concentrations are listed in Table 2. Students can choose additional courses to fulfill their concentration requirement as new courses become available, as long as they receive approval, in advance, from the Professional Engineering Program Director.

Table 1. Professional Engineering Option Credit Distribution

Bioengineering Concentration	Credits
3 Core Courses in CHE	9
2 Chemical Engineering Electives[1]	6
Concentration:	
CHE 521: Biochemical Engineering	3
2 Concentration Courses	6
CHE 590: GQP	6
Total	**30**
Advanced Process Engineering Concentration	**Credits**
3 Core Courses in CHE	9
2 Chemical Engineering Electives[1]	6
Concentration:	
CHE 565: Advanced Process Engineering	3
2 Concentration Courses	6
CHE 590: GQP	6
Total	**30**

[1]Students may choose to take one of these courses in the topic of innovation to gain additional experience in business and for preparation for the GQP, including ETR 500. Entrepreneurship and Innovation. Students should get approval from the Faculty Director for course substitution.

Return to Table of Contents

Table 2: Possible Concentration Courses

Bioengineering
BCB 501. Bioinformatics
BCB 502. Biovisualization
BCB 503. Biological and Biomedical Database Mining
BCB 504. Statistical Methods in Genetics and Bioinformatics
BB 505. Fermentation Biology
BB 509. Scale Up of Bioprocessing
BB 560. Methods of Protein Purification and Downstream Processing
BB 562. Cell Cycle Regulation
BME 523. Biomedical Instrumentation
BME/ME 550. Tissue Engineering
CH 538. Medicinal Chemistry
CH 540. Regulation of Gene Expression
BB 565. Virology
BB 575. Advanced Genetics and Cellular Biology
BME 552/ME 552. Tissue Mechanics
CE 562. Biosystems in Environmental Engineering
Advanced Process Engineering
CHE 504. Mathematical Analysis in Chemical Engineering[2]
CHE 509. Reactor Design and Kinetics[2]
CHE 531. Fuel Cell Technology
DS 501. Introduction to Data Science
FP 521. Fire Dynamics I
FP 553. Fire Protection Systems
FP 554. Advanced Fire Suppression
FP 555. Detection, Alarm and Smoke Control
FP 573. Industrial Fire Protection
FP 575. Explosion Protection
MFE 510/ ME 542. Control and Monitoring of Manufacturing Processes
MFE 520/ MTE 520/ME 543. Design and Analysis of Manufacturing Processes
MFE/MTE/ME 5420. Fundamentals of Axiomatic Design of Manufacturing Processes
MTE 558. Plastics
MTE 5844. Corrosion and Corrosion Control
ME 516. Heat Transfer
ME/AE 5220. Control of Linear Dynamical Systems
ME/AE 5221. Control of Nonlinear Dynamical Systems
SD 550. System Dynamics Foundation: Managing Complexity
SD 553. Model Analysis and Evaluation Techniques
SYS 501. Concepts of Systems Engineering
SYS 502. Business Practices
SYS 510. Systems Architecture and Design
SYS 512. Requirements Engineering
SYS 520. System Optimization
SYS 521. Model-Based Systems Engineering
SYS 540. Introduction to Systems Thinking

[2]Can be used to satisfy concentration requirements if not taken as part of the core.

Table 3: Core Courses

Core Courses (choose 3)
CHE 504: Mathematical Analysis in Chemical Engineering
CHE 509. Reactor Design and Kinetics
CHE 561: Thermodynamics
CHE 571: Transport Phenomena

Thesis Option

A total of 30 credit hours is required, including 18 credit hours of coursework and at least 12 credit hours of thesis work. The coursework must include 15 credit hours of graduate level chemical engineering courses and 9 of these must be chosen from the core curriculum. A satisfactory oral seminar presentation must be given every year in residence.

Non-Thesis Option

A total of 30 credit hours is required, including a minimum of 24 credit hours in graduate level courses. At least 21 course credit hours must be in chemical engineering and 9 of these must be chosen from the core curriculum. A maximum of 6 credit hours of independent study under the faculty advisor may be part of the program. *Any advanced undergraduate level courses must be approved by the departmental Graduate Committee.*

The Combined B.S./M.S. Program

Double Counting. B.S.-M.S. students may double-count up to 12 credits from undergraduate or graduate courses. A maximum of four undergraduate courses may be double-counted. The undergraduate courses allowed to double-count are listed below. Students may also petition the graduate committee for other 4000-level courses to double-count. A minimum grade of "B" is required for the course to be double-counted. In order for a course to be double-counted, students must also complete an extra assignment for each course demonstrating graduate-level competence. This extra assignment may be for instance a project or a literature review. The instructor for each course should advise the student what this assignment would be after being notified that the student is double counting the course towards the B.S.-M.S. degree. Students must be accepted into the B.S.-M.S. program before courses are allowed to double-count.

Allowed Undergraduate Courses (Four Maximum Allowed to Double-Count)

- CHE 3501 Applied Mathematics in Chemical Engineering
- CHE 4405 Chemical Process Dynamics and Control Laboratory
- MQP Major Qualifying Project (1/3 unit maximum)
- An Independent Study in Chemical Engineering at the 4000 level (1/3 unit maximum)

Only One of the Following May Count:

- CHE 4401 Unit Operations of Chemical Engineering I
- CHE 4402 Unit Operations of Chemical Engineering II

Only One of the Following May Count:

- CHE 4404 Chemical Plant Design Project
- CHE 4410 Chemical Process Safety Design

For the Ph.D.

Upon completion of the comprehensive qualifying examination, candidates must present a research proposal in order to acquaint members of the faculty with the chosen research topic.

Chemical Engineering Research Centers and Laboratories

Research is housed in both Goddard Hall and Gateway Park (Life Sciences and Bioengineering Center; LSBC). The LSBC is a four-story, 125,000-square-foot interdisciplinary research building that houses life sciences faculty in the departments of Biology and Biotechnology, Biomedical Engineering, Chemistry and Biochemistry, Chemical Engineering and Physics. Both Goddard Hall and LSBC are equipped with state of the art instrumentation and core facilities to support catalysis and reaction engineering work and bioengineering work, respectively. In addition, the Chemical Engineering Department participates in and/or leads a number of research center efforts on campus including the Energy Research Center, Center for Advanced Research in Drying, Biomanufacturing Education and Training Center, Fuel Cell Center, and Metal Processing Institute.

Return to Table of Contents

Course Descriptions

All courses are 3 credits unless otherwise noted.
*Core chemical engineering courses.

CHE 501-502. Seminar
(0 credits)
Reports on current advances in the various branches of chemical engineering or on graduate research in progress. Must be taken during every semester in residence.

CHE 503. Colloquium
(0 credits)
Presentations on scientific advances by recognized experts in various fields of chemical engineering and related disciplines. The course will be graded on a Pass/Fail basis.

CHE 504. Mathematical Analysis in Chemical Engineering•
An essential skill of an engineer is to provide analytical and numerical solutions to relevant problems. This course will provide students with a solid mathematical background required to solve chemical engineering problems in fields such as fluid mechanics, reactor design, thermodynamics, and process design. Methods of mathematical analysis relevant to engineering will be selected from such topics as vector analysis, matrices, eigenvalue problems, Fourier analysis, Fourier transforms, Laplace transformation, solution of ordinary and partial differential equations, integral equations, calculus of variation, optimization methods, and numerical methods. Students should have a background in undergraduate calculus and differential equations.

CHE 509. Reactor Design and Kinetics*
This course includes a review of prototypical chemical reactors, including design of batch, stirred tank, and tubular reactors. Theories of reaction kinetics and catalysis for simple and complex reactions are addressed. Reactor design is discussed within the context of complex transport phenomena and reaction kinetics, including effects of bulk and pore diffusion and multiphase reactions/reactors. Techniques for experimentation, reaction data treatment, catalyst preparation and characterization, and computational tools are also included. Students cannot receive credit for this course and CHE 506 or CHE 507, which this class replaces.

CHE 510. Dynamics of Particulate Systems
Analyzes discrete particles which grow in size or in some other characteristic variable (e.g., age, molecular weight). Reaction engineering and population balance analyses for batch and continuous systems. Steady state and transient system dynamics. Topics may include crystallization, latex synthesis, polymer molecular weight distribution, fermentation/ ecological systems and gas-solid systems.

CHE 515. Research Analysis and Design
Effective research requires understanding methods of data collection and analysis. Students will learn to apply statistical methods to analyzing data, develop mathematical models from data, visually present information, and design experiments to maximize the gain of useful information. Emphasis will also be on performing research ethically and according to accepted practices. Other topics that may be covered include: efficient use of the literature, creating and testing a hypothesis, making sound arguments, and preparing results for publication. Students should have a background in calculus. Students may not receive credit if they previously completed this course as CHE 580: Special Topics.

CHE 521. Biochemical Engineering
Ligand binding and membrane transport processes, growth kinetics of animal cells and micro-organisms, kinetics of interacting multiple populations, biological reactor design and analysis, soluble immobilized enzyme kinetics, optimization and control of fermentation, biopolymer structure and function, properties of biological molecules, biological separation processes, scale-up of bioprocesses; laboratory work may be included when possible.

CHE 531. Fuel Cell Technology
The course provides an overview of the various types of fuel cells followed by a detailed discussion of the proton-exchange membrane (PEM) fuel cell fundamentals: thermodynamics relations including cell equilibrium, standard potentials, and Nernst equation; transport and adsorption in proton-exchange membranes and supported liquid electrolytes; transport in gas-diffusion electrodes; kinetics and catalysis of electrocatalytic reactions including kinetics of elementary reactions, the Butler-Volmer equation, reaction routes and mechanisms; kinetics of overall anode and cathode reactions for hydrogen and direct methanol fuel cells; and overall design and performance characteristics of PEM fuel cells.

CHE 554/CH 554. Molecular Modeling
This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical applications, for researchers who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a backround at the introductory level in quantum mechanics is highly desirable. Methods to be explored include density functional theory, *ab initio* methods, semiempirical molecular orbital theory, and visualization software for the graphical display of molecules.

CHE 561. Thermodynamics*
Thermodynamics is at the heart of many systems of interest to chemical engineers, from the efficiency of simple mechanical processes to the equilibria of complex reactions. This course is a rigorous treatment of classical thermodynamics, with reference to the field of statistical thermodynamics. Key modules include First and Second Law analysis; behavior and interrelationships of thermodynamic properties; and fluid phase and chemical equilibria. Example topics may include analysis of open and dynamic systems; fundamental relationships; Legendre transforms and generalized potentials; Maxwell relationships; stability theory; thermodynamics of mixtures; fugacity, activity, and chemical potential; phase equilibria of systems containing two or more components; and generalized treatment of chemical equilibria.

CHE 565. Advanced Process Engineering
Advanced topics in process synthesis, optimization and process control are examined. Optimization topics include objective functions, multivariable optimization, constrained optimization, mixed integer linear programming and applications of optimization to process industries. Control topics include model predictive control, adaptive control, batch process control, and plant-wide control. Recommended background: Undergraduate degree in Chemical Engineering.

CHE 571. Transport Phenomena*
Transport rates of mass, energy, and momentum are key to the design of many chemical technologies. This class adopts a unified approach to transport phenomena, providing the fundamental background required for analysis of complex problems. Students will use mathematical techniques for analytic and approximate solutions such as: separation of variables, similarity solutions, perturbation theory, and Laplace and Fourier transform methods. Methods involving non-dimensionalization and scaling will be emphasized. Special problems to be covered may include the lubrication approximation, creeping flow, and potential and laminar boundary-layer flows, as well as heat and mass transport in multi-component systems. Students are expected to have taken previous courses on transport processes and have mathematical background that includes solution of differential equations.

CHE 580. Special Topics
This course will focus on various topics of current interest related to faculty research experience.

CHE 590. Graduate Qualifying Project in Chemical Engineering
(3 or 6 credits)
These courses provide a capstone experience in applying chemical engineering skills to real-world problems. The Graduate Qualifying Project (GQP) is carried out with an industrial partner or sponsoring agency and with the approval and oversight of a faculty member in chemical engineering. A written report and a presentation to members of the department and industrial partners are required. (Pre-requisites: Completion of core requirements, at least one concentration course and consent of the program director.) Recommended background: Undergraduate degree in Chemical Engineering, completion of the core requirements and at least one concentration course.

**Core chemical engineering courses.*

Return to Table of Contents

Chemistry and Biochemistry

Faculty

A. Gericke, Professor and Department Head; Dr.rer.nat., University of Hamburg; biophysical characterization of lipid-mediated protein function, development of vibrational spectroscopic tools to characterize biological tissue.

J. M. Argüello, Professor; Ph.D., Universidad Nacional de Río Cuarto, Argentina; transmembrane ion transport, metal-ATPases structure-function, bacterial metal homeostasis, role os metals in bacterial pathogenesis.

S. C. Burdette, Associate Professor; Ph.D., Massachusetts Institute of Technology; synthesis of fluorescent sensors for iron, photoactive chelators for delivery of metal ions in cells, applications of azobenzene derivatives with unusual optical properties, polymers to detect metal contaminants in the environment.

R. E. Dempski, Associate Professor; Ph.D., Massachusetts Institute of Technology; molecular mechanism of human zinc transporter, structure-function of light activated channel, optogenetics.

J. P. Dittami, Professor; Ph.D., Rensselaer Polytechnic Institute; medicinal chemistry, organic synthesis, new synthetic methods development.

R. L. Grimm, Assistant Professor; Ph.D., California Institute of Technology; growth and characterization by surface science and by photoelectrochemistry of non-traditional semiconductor materials related to solar energy capture, catalysis, and conversion.

G. A. Kaminski, Associate Professor; Ph.D., Yale University; computational physical and biophysical chemistry, force field development, protein structure and binding, host-guest complex formation, solvation effects.

J. MacDonald, Associate Professor; Ph.D., University of Minnesota; porous crystalline materials composed of organic & coordination compounds, polymorphism of pharmaceutical drugs, crystallization of proteins, surpramolecular assembly on surfaces.

A. Mattson, Professor; Ph.D., Northwestern University; metal-free catalyst design, methodology development, complex molecule synthesis.

C. Perez Olsen, Assistant Professor; Ph.D., University of Washington; characterization of membrane composition by mass spectrometry, quantification of lipid flux with stable isotope tracers, genetic dissection of the regulatory pathways of membrane maintenance.

S. F. Scarlata, Professor, Ph.D., University Illinois Urbana-Champaign; Mechanisms of cell signaling using fluorescence imaging and correlation methods, how mechanical deformation affects calcium fluxes in cells.

P. Zhang, Assistant Professor; Ph.D., Princeton University; catalysis, methodology development, complex molecule synthesis.

Research Interests

The three major areas of research in the department are:

- Biochemistry and Biophysics. Within this area there is active research on a number of topics including heavy metal transport and metal homeostasis of both plants and bacteria, computational biochemistry/biophysics of membrane proteins, enzyme structure and function, and G protein and calcium signaling, membrane protein domains and mechanotransduction.
- Molecular Design and Synthesis. Within this area there is active research on topics encompassing organic synthesis and medicinal chemistry, supramolecular materials, metal ion sensors and chelators, polymorphism in pharmaceutical drugs, spectroscopy and photophysical properties of molecules, catalysis for C-H functionalization, and more.
- Nanotechnology and Materials. This research area encompasses such projects as photonic and nonlinear optical materials, nanoporous and microporous crystals of organic and coordination compounds, molecular interactions at surfaces, and others.

Programs of Study

The Department of Chemistry and Biochemistry offers the M.S. and Ph.D. in both Chemistry and Biochemistry. The major areas of research in the department are biochemistry and biophysics, molecular design and synthesis, and nanotechnology and materials.

Admission Requirements

A B.S. degree with demonstrated proficiency in chemistry or biochemistry is required for entrance to Chemistry and Biochemistry graduate programs.

Degree Requirements

Each student must take at least three core courses in their self-identified home track (biochemistry, inorganic, organic, physical), at least three elective courses either from an approved list of classes or pre-approved by the CBC graduate committee, as well as seminar courses. Entering students who have deficiencies in specific areas (inorganic, organic, physical, or biochemistry), as revealed by entrance interviews, will take appropriate courses to correct these deficiencies.

Ph.D. students should select a research advisor no later than at the end of the first semester of residence, and M.S. students should select an advisor no later than at the end of the first term (first seven weeks).

For the M.S.

For the Master of Science in Chemistry or Biochemistry, the student is required to complete a minimum of 30 graduate credit hours beyond the bachelor's degree. Students may choose between a thesis or non-thesis option. In addition to general college requirements, all courses taken for graduate credit must result in a GPA of 3.0 or higher.

Thesis Option

The student must complete a thesis with at least 15 combined credits CH 598 (Directed Research) or CH 599 (M.S. Thesis). Additional credits may consist of any combination of thesis or course electives. Course elective credits must

Return to Table of Contents

consist of additional CBC or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. All course selections must be approved by the student's research advisor and the CBC Graduate Committee prior to registering. Each student should select a research advisor by the end of the first semester of study. M.S. candidates must submit and defend a thesis based on research conducted under the direction of a CBC faculty member. The thesis committee consists of at least three members, two of whom must belong to the CBC Department faculty.

Non Thesis Option

Graduate credits must consist of 4000-, 500- or 600-level courses. Credits should be distributed as follows:

- At least 15 credits in CBC courses.
- A maximum of 10 credits in electives in areas of engineering, science, management or mathematics.
- Students also may use up to 9 credits of CH 598 (Directed Research) toward credit hour requirements.

Biochemistry students will be advised to take graduate courses in Membrane Biophysics (CH 541), Molecular Modeling (CH 554), Medicinal Chemistry (CH 538), and Spectroscopy (CH 516) in addition to advanced Biochemistry courses. Among electives in other areas, these might include courses on applied Biochemistry/Biological processes (BB 560/ BB 505/BB 509) and Bioinformatics (BCB 501/BCB 502/BCB 503).

Chemistry students will be advised to take graduate courses in Theory and Applications of NMR Spectroscopy (CH 536), Molecular Modeling (CH 554), Medicinal Chemistry (CH 538), and Spectroscopy (CH 516) in addition to advanced Chemistry courses. Among electives in other areas, these might include courses on Chemical Engineering (CHE 506/ CHE 521/CHE 561) applied Biochemistry/Biological processes (BB 560/BB 505/BB 509).

B.S./M.S. Degree

The Department of Chemistry and Biochemistry offers a combined B.S./M.S. degree option for undergraduate students currently enrolled at WPI. The university rules for B.S./M.S. programs are described in Section 5 of the undergraduate catalog and on page 21 of the graduate catalog.

The M.S. degree requirements for the B.S./M.S. program are the same as the requirements for the course work-based M.S. degree that already exists in the Department of Chemistry and Biochemistry. A B.S./M.S. degree can be completed in either 4 years (course work based M.S.) or 5 years (course work or research based M.S.). Students may formally apply to the B.S./M.S. program through the graduate admissions office or via their website.

For the Ph.D.

Each student should select a research advisor by the end of the first semester of residence. By the end of the second year of residence, the student must submit a written and an oral progress report in the dissertation committee of at least four faculty members, including the Research Advisor, at least two more members of the Department, and at least one person from outside the Department. The committee will consider the student's progress and will recommend to the department whether the student should be allowed to continue toward a Ph.D.

Students who do not satisfy the academic milestones described in the Departmental Handbook (e.g., maintaining a departmental GPA over 3.0, finding a mentor, passing the qualifying exam, etc.), as determined by the department, will be dismissed from the program.

Qualifying Examination

Before formal admission to the doctoral candidacy, Ph.D. students must take the qualifying examination in their field of specialization. The examination should take place before the end of the second year of residence.

Dissertation

To fulfill the final Ph.D. degree requirement the candidate must submit and defend a satisfactory dissertation to the dissertation committee.

Chemistry and Biochemistry Research Laboratories

The Chemistry and Biochemistry Research Laboratories are located in Goddard Hall and at Gateway Park. Department facilities and instrumentation in individual research laboratories include 500 and 400 MHz FT-NMR, GC-MS, GC, HPLC, capillary electrophoresis, DSC (differential scanning calorimeter), TGA (thermogravometric analysis), polarizing optical stereomicroscope, FT-IR, UV-VIS absorption, fluorescence and phosphorescence spectroscopy; powder and single crystal x-ray diffractometers, cyclic voltammetry, impedence spectroscopy, ellipsometer, quartz crystal microbalance, grazing incidence IR, atomic force microscope (AFM), and other surface-related facilities. Additional equipment in the biochemistry area include: centrifugues, ultra-centrifugues, PCR, phospho imager, scintillation counter, FPLC, bacteria and eukaryotic cell culture and plant growth facilities. The department is exceptionally well set up with computer facilities and is also linked to the University's network.

Course Descriptions

All courses are 3 credits unless otherwise noted.

CH 516. Chemical Spectroscopy

The emphasis is on using a variety of spectroscopic data to arrive at molecular structures, particularly of organic molecules. Major emphasis is on H- and C-NMR, IR and MS. There is relatively little emphasis on theory or on sampling handling techniques.

CH 536. Theory and Applications of NMR Spectroscopy

This course emphasizes the fundamental aspects of 1D and 2D nuclear magnetic resonance spectroscopy (NMR). The theory of pulsed Fourier transform NMR is presented through the use of vector diagrams. A conceptual nonmathematical approach is employed in discussion of NMR theory. The course is geared toward an audience which seeks an understanding of NMR theory and an appreciation of the practical applications of NMR in chemical analysis. Students are exposed to hands-on NMR operation. Detailed instructions are provided and each student is expected to carry out his or her own NMR experiments on a Bruker AVANCE 400 MHz NMR spectrometer.

CH 538. Medicinal Chemistry

This course will focus on the medicinal chemistry aspects of drug discovery from an industrial pharmaceutical research and development perspective. Topics will include chemotherapeutic agents (such as antibacterial, antiviral and antitumor agents) and pharmacodynamic agents (such as antihypertensive, antiallergic, antiulcer and CNS agents). (Prerequisite: A good foundation in organic chemistry, e.g., CH 2310 Organic Chemistry I and CH 2320 Organic Chemistry II.)

CH 540. Regulation of Gene Expression

(2 credits)

This course covers the biochemical mechanisms involved in regulation of gene expression: modifications of DNA structures that influence transcription rates, transcriptional regulation, post-transcriptional processing of RNA including splicing and editing, nuclear/cytoplasmic transport, regulation of translation, and factors that control the half-lives of both mRNA and protein. During the course, common experimental methods are explored, including a discussion of the information available from each method.

CH 541. Membrane Biophysics

(2 credits)

This course will focus on different areas of biophysics with special emphasis on membrane phenomena. The biomedical-biological importance of biophysical phenomena will be stressed. The course will begin with an introduction to the molecular forces relevant in biological media and subsequently develop the following topics: membrane structure and function; channels, carriers and pumps; nerve excitation and related topics; and molecular biophysics of motility. Topics will be developed assuming a good understanding of protein and lipid chemistry, enzyme kinetics, cell biology, and electricity.

CH 542. Drugs in the Brain

This class will introduce the concepts of basic neuropharmacology and the action of major neurotransmitter families in the brain. The mechanisms of action of the major psychoactive drugs families including cannabis, opioids, and psychedelics will be covered. The effects of pharmaceutical treatments for anxiety and depression on brain chemistry will be discussed as well. This course will be offered in 2020-2021 and alternating years thereafter.
Recommended Background: Fundamental understanding of introductory biochemistry (CH4110, CH4120, and/or CH4130).

CH 543. Organometallic Chemistry and Catalysis

Organometallic chemistry and catalytic reactions have fundamentally changed the way drugs and polymeric materials are made today. Furthermore, they have enabled the synthesis and application of new electronic materials (e.g. in OLEDs and molecular wires) and materials mimicking natural processes (e.g. self-healing and anti-bacterial coatings). This course will establish principles to understand the reactivity of organometallic compounds of transition and main groups metals. Furthermore, metal-free catalysis will be introduced. Pulling on influences from both inorganic and organic chemistry, the class will provide insight into catalysis approaches that have revolutionized synthetic chemistry, enabling highly efficient, sustainable production of compounds that are used in such different areas as drug discovery, protein analysis, and performance plastics. Case studies will be drawn from the current literature and applications that are widely used in industrial and academic settings and will include work that has led to recent Nobel prizes in the area. Recommended preparation includes the organic chemistry sequence (CH2310, CH2320, and CH2330) and CH3410. The course is recommended for both graduate and advanced undergraduate students. This course will be offered in 2018-2019 and alternate years thereafter.

CH 544. Elucidation of Organic Reaction Mechanisms

In this advanced course, students will develop skill sets to independently understand, explain, and predict reactions of organic molecules. Principles of modern physical organic chemistry, such as bonding, hybridization, molecular orbital theory, non-covalent interactions, stereochemistry, and conformational analysis, will be introduced along-side experimental techniques related to thermo-dynamics and kinetics to provide scientists with tools to understand existing reaction pathways and study new reactions. The interplay between mechanistic hypotheses and experimental observa-tions will be demonstrated using case studies from the primary literature. Recommended for graduate students and undergraduates who have completed the sequence in organic chemistry (CH2310, CH2320, and CH2330). This course will be offered in 2019-2020 and alternating years thereafter.

CH 545. Plant Natural Products

This class will cover the chemistry of a number of families of plant-derived natural products, including, terpenoids, phenolic compounds, and alkaloids. The coverage of aspects of the chemistry involving these natural products may include biosynthesis, chemical synthesis, and medicinal chemistry applications. The historical and current roles of select natural products, such as tetrahydrocannabinol, taxol, heroin, and quinine, in society may also be discussed. This class will be offered in 2020-2021 and alternating years thereafter.
Recommended background: A fundamental understanding of organic chemistry, such as that obtained in an introductory organic chemistry sequence (CH2310, CH2320, and CH2330).

CH 546. Natural Product Isolation and Analysis

In this laboratory class, students will learn strategies to isolate and characterize natural products. Techniques used during this course may include solvent extraction, supercritical fluid extraction, NMR spectroscopy, IR spectroscopy, mass spectrometry, gas chromatography, and liquid chromatography. This class will be offered in 2021-2022 and alternating years thereafter. Recommended background: Introductory chemistry laboratory experience.

CH 554/CHE 554. Molecular Modeling

This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be toward practical applications, for researchers who want to answer specific questions about molecular geometry, transition states, reaction paths and photoexcited states. No experience in programming is necessary; however, a backround at the introductory level in quantum mechanics is highly desirable. Methods to be explored include density functional theory, *ab initio* methods, semiempirical molecular orbital theory, and visualization software for the graphical display of molecules.

CH 555. Advanced Topics

(1 to 3 credits as arranged)

A course of advanced study in selected areas whose content and format varies to suit the interest and needs of faculty and students. This course may be repeated for different topics covered.

CH 560. Current Topics in Biochemistry

(1 credit per semester)

In this seminar course, a different topic is selected each semester. Current articles are read and analyzed.

CH 561. Functional Genomics

(1 credit per semester)

In this seminar course, students will present and critically analyze selected, recent publications in functional genomics. The course will conclude with a written project, either a mini-grant proposal or an analysis of publicly available data in a research manuscript format. The course will be offered in alternate years in lieu of CH 560, may be repeated as many times as offered, and satisfies the department's requirement for a graduate seminar in biochemistry. *This course is offered by special arrangement only, based on expressed student interest.*

CH 571. Seminar

(1 credit per semester)

Reports on current advances in the various branches of chemistry.

CH 598. Directed Research

CH 599. M.S. Thesis

CH 699. Ph.D. Dissertation

The following graduate/undergraduate chemistry courses are also available for graduate credit.

CH 4110. Biochemistry I

The principles of protean structure are presented. Mechanisms of enzymatic catalysis, including those requiring coenzymes, are outlined in detail. The structures and biochemical properties of carbohydrates are reviewed. Bioenergetics, the role of ATP, and its production through glycolysis and the TCA cycle are fully considered.

CH 4120. Biochemistry II

Oriented around biological membranes, this term begins with a discussion of electron transport and the aerobic production of ATP, followed by a study of photosynthesis. The study of the biosynthesis of lipids and steroids leads to a discussion of the structure and function of biological membranes. Finally, the membrane processes in neurotransmission are discussed. (Recommended background: CH 4110.)

CH 4130. Biochemistry III

This course presents a thorough analysis of the biosynthesis of DNA (replication), RNA (transcription) and proteins (translation), and of their biochemical precursors. Proteins and RNAs have distinct lifetimes within the living cell; thus the destruction of these molecules is an important biochemical process that is also discussed. In addition to mechanistic studies, regulation of these processes is covered.

CH 4330. Organic Synthesis

Modern synthetic methods as applied to the construction of societally relevant target molecules will be the focus of this course. Discussions may emphasize the logic and strategy in synthetic approaches toward active pharmaceutical ingredients, agrochemicals, fine chemicals, materials, and other targets of interest. The analysis of current examples from the primary literature will draw attention to the most state-of–the-art synthetic tactics. Recommended for graduate students and undergraduates who have a basic understanding of the principles governing organic reactions, such as those covered in CH2310, CH2320, and CH2330. This course will be offered in 2018-19 and alternate years thereafter.

CH 4420. Inorganic Chemistry II

Complexes of the transition metals are discussed. Covered are the electronic structures of transition metal atoms and ions, and the topological and electronic structures of their complexes. Symmetry concepts are developed early in the course and used throughout to simplify treatments of electronic structure. The molecular orbital approach to bonding is emphasized. The pivotal area of organotransition metal chemistry is introduced, with focus on complexes of carbon monoxide, metal-metal interactions in clusters, and catlysis by metal complexes. (Recommended background: CH 2310 and CH 2320, or equivalent.) This course will be offered in 2019-20 and in alternate years thereafter.

CH 4520. Chemical Statistical Mechanics

This course deals with how the electronic, translational, rotational and vibrational energy levels of individual molecules, or of macromolecular systems are statistically related to the energy, entropy and free energy of macroscopic systems, taking into account the quantum mechanical properties of the component particles. Ensembles, partition functions, and Boltzmann, Fermi/Dirac and Bose-Einstein statistics are used. A wealth of physical chemical phenomena, including material related to solids, liquids, gases, spectroscopy and chemical reactions are made understandable by the concepts learned in this course. This course will be offered in 2019-20 and in alternate years thereafter.

Return to Table of Contents

Civil and Environmental Engineering

Faculty

C. Eggleston, Professor & Department Head; Ph.D., Stanford University; natural materials and how they interact with the environment in which we live, focusing on the fundamental processes of adsorption, dissolution/growth, electron transfer, and catalysis.

L. Abu-Lail, Assistant Professor of Teaching, Ph.D., Worcester Polytechnic Institute; Unit Operations of Chemical Engineering, Water Treatment, Hydraulics, Environmental Organic Chemistry.

L. D. Albano, Associate Professor; Ph.D., Massachusetts Institute of Technology; performance-based design of buildings, design and behavior of building structures in fire conditions, integration of design and construction.

J. Bergendahl, Associate Professor; Ph.D., University of Connecticut; industrial and domestic wastewater treatment, particulate processes in the environment, chemical oxidation of contaminants.

J. Dudle, Associate Professor; Ph.D., University of Massachusetts Amherst; surface water quality, drinking water treatment, public health.

T. El-Korchi, Professor; Ph.D., University of New Hampshire; glass fiber reinforced cement composites, tensile testing techniques, materials durability.

S. Farzin, Assistant Professor of Teaching, Ph.D., University of Massachusetts Amherst; Architectural Design, Sustainable Building Technologies, Urban Metabolism, Net Zero Emission Neighborhood, Building Energy Simulation, Art installation, Music.

S. Liu, Assistant Professor, Ph.D., University of Texas at Austin; indoor air quality, thermal comfort, building energy efficiency, computational fluid dynamics.

R. B. Mallick, Professor and White Chair; Ph.D., Auburn University; nondestructive testing, highway design, pavement material characterization.

P. P. Mathisen, Associate Professor; Ph.D., Massachusetts Institute of Technology; water resources and environmental fluid dynamics, contaminant fate and transport in groundwater and surface water, exchanges across the sediment-water interface.

N. Rahbar, Associate Professor; Ph.D., Princeton University; atomistic simulations, bioinspired design of materials, contact mechanics and adhesion, computational material science.

A. Sakulich, Associate Professor; Ph.D., Drexel University; sustainability of infrastructure materials, alternative binders, and advanced civil engineering systems.

M. Tao, Associate Professor; Ph.D., Case Western Reserve University; soil mechanics, geotechnical-pavement engineering, geo-material characterization and modeling.

S. Van Dessel, Associate Professor; Ph.D., University of Florida, Gainesville; architectural engineering, building materials.

H. Walker, Schwaber Professor of Environmental Engineering, Ph.D., University of California, Irvine; water quality, emerging contaminants, water and wastewater treatment, environmental nanotechnology, membrane processes.

Programs of Study

The Department of Civil and Environmental Engineering (CEE) offers graduate programs leading to the degrees of master of science, master of engineering and doctor of philosophy. The department also offers graduate and advanced certificate programs. Full- and part-time programs of study are available.

Master of Science and Doctor of Philosophy

The graduate programs in civil engineering and environmental engineering are arranged to meet the interests and objectives of the individual student. Through consultation with an advisor and appropriate selection from the courses listed in this catalog, independent graduate study and concentrated effort in a research or project activity, a well-planned program may be achieved. Students may take acceptable courses in other departments or those approved for graduate credit. The complete program must be approved by the student's advisor and the Graduate Program Coordinator.

The faculty have a broad range of teaching and research interests. Through courses, projects and research, students gain excellent preparation for rewarding careers in many sectors of engineering including consulting, industry, government and education.

Graduate programs may be developed in the following areas:

Structural Engineering

Courses from the structural offerings, combined with appropriate mathematics, mechanics and other courses, provide opportunities to pursue programs ranging from theoretical mechanics and analysis to structural design and materials research. There are ample opportunities for research and project work in mechanics, structures and construction utilizing campus facilities and in cooperation with area consulting and contracting firms. The integration of design and construction into a cohesive master builder plan of studies is available. (See page 74).

Some current and recent structural engineering research topics at WPI include: structural vibration control; structural health monitoring; system identification; design and analysis of smart structures; high impact response analysis; control and monitoring; three-dimensional dynamic response of tall buildings to stochastic winds; the inelastic dynamic response of tall buildings to earthquakes; evaluation of structural performance during fire conditions; structural design agents for building design; finite element methods for nonlinear analysis; finite element analysis of shell structures for dynamic and instability analysis; and box girder bridges.

Environmental Engineering

The environmental engineering program is designed to meet the needs of engineers and scientists in the environmental field. Coursework provides a strong foundation in both the theoretical and practical aspects of the environmental engineering discipline, while project and research activities allow for in-depth investigation of current and emerging topics. Courses are offered in the broad areas of water quality and waste treatment. Topics covered in classes include: hydraulics and hydrology; physical, chemical and biological treatment systems for water, wastewater, hazardous waste and industrial waste; modeling of contaminant transport and transformations; water quality and water resources.

Current research interests in the environmental engineering program span a wide range of areas. These areas include microbial contamination of source waters, colloid and surface chemistry, physiochemical treatment processes, disinfection, pollution prevention for industries, treatment of hazardous and industrial wastes, hydraulic and environmental fluid dynamics and coastal processes, contaminant fate and transport in groundwater and surface water, exchanges between surface and subsurface waters, and storm water quality control. Research facilities include the Environmental Laboratory and several computing laboratories. Additional opportunities are provided through collaborative research projects with nearby Alden Research Laboratory, an independent hydraulics research laboratory with large-scale experimental facilities.

Geotechnical Engineering

Course offerings in soil mechanics, geotechnical and geoenvironmental engineering may be combined with structural engineering and engineering mechanics courses, as well as other appropriate university offerings.

Engineering and Construction

Designed to assist the development of professionals knowledgeable in the design/construction engineering processes, labor and legal relations, and the organization and use of capital. The program has been developed for those students interested in the development and construction of large-scale facilities. The program includes four required courses: CE 580, CE 584, CE 587 and FIN 500. (FIN 500 can be substituted by an equivalent 3-credit-hour course approved by the department.) It must also include any two of the following courses: CE 581, CE 582, CE 583 and CE 586. The remaining courses include a balanced choice from other civil engineering and management courses as approved by the advisor. It is possible to integrate a program in design and construction to develop a cohesive master builder plan of studies. Active areas of research include integration of design and construction, models and information technology, cooperative agreements, and international construction.

Transportation Engineering

The transportation engineering program is to provide a center for education and research for the engineers who will design, build and conduct cutting-edge research on transportation infrastructure.

The transportation engineering program is a multidisciplinary interdepartmental program designed to prepare students for careers designing, maintaining and managing transportation infrastructure systems. Students gain proficiency in transportation engineering in two complementary ways: projects and coursework. Projects focus on developing improved practical methods, procedures and techniques. Coursework is focused on practical aspects of infrastructure technology needed by practicing engineers.

Research in the transportation engineering program is sponsored by a variety of private and governmental organizations including the U. S. Federal Highway Administration, the National Cooperative Highway Research Program, the Massachusetts Highway Department, The Maine Department of Transportation, the New England Transportation Consortium, the National Science Foundation and others. Some of the more active research areas being pursued in the transportation engineering program include micro/nano characterization and micro/nano mechanics of construction materials, synthesizing 'greener' cementitious materials (geopolymers) from industrial wastes, understanding fundamental behavior of granular materials, energy harvesting from pavements, reduction of pavement temperatures and urban heat island effects, high reclaimed asphalt pavement (RAP) recycling, use of geosynthetics, phase changing materials, Superpave technology, pavement smoothness and ride quality measurement, recycled asphalt materials, and implementation of innovation in transportation management and other transportation-related topics.

Interdisciplinary M.S. Program in Construction Project Management

The interdisciplinary M.S. program in construction project management combines offerings from several disciplines including civil engineering, management science, business and economics. Requirements for the degree are similar to the master of science in engineering and construction management program.

Master of Engineering

The master of engineering degree is a professional practice-oriented degree. The degree is available both for WPI undergraduate students who wish to remain at the university for an additional year to obtain both a bachelor of science and a master of engineering, as well as for students possessing a B.S. degree who wish to enroll in graduate school to seek this degree. At present, the M.E. program is offered in the following two areas of concentration.

Master Builder

The master builder program is designed for engineering and construction professionals who wish to better understand the industry's complex decision-making environment and to accelerate their career paths as effective project team leaders.

This is a practice-oriented program that builds upon a project-based curriculum and uses a multidisciplinary approach to problem solving for the integration of planning, design, construction and facility management. It emphasizes hands-on experience with information technology and teamwork.

Environmental

The environmental master of engineering program concentrates on the collection, storage, treatment and distribution of industrial and municipal water resources and on pollution prevention and the treatment and disposal of industrial and municipal wastes.

Admission Requirements

For the M.S.

An ABET accredited B.S. degree in civil engineering (or another acceptable engineering field) is required for admission to the M.S. program in civil engineering. Applicants are expected to have the necessary academic preparation and aptitude to succeed in a challenging graduate program. Students who do not have an ABET accredited B.S. degree may wish to enroll in the inderdisciplinary M.S. program.

For the environmental engineering program, a B.S. degree in civil, chemical or mechanical engineering is normally required. However, students with a B.S. in other engineering disciplines as well as physical and life sciences are eligible, provided they have met the undergraduate math and science requirements of the civil and environmental engineering program. A course in the area of fluid mechanics is also required. As for the civil engineering degree program, applicants are expected to have the necessary background preparation and aptitude to succeed in a challenging graduate program. All graduates of this option will receive a master of science in environmental engineering.

For the interdisciplinary M.S. program in construction project management, students with degrees in areas such as architecture, management engineering and civil engineering technology are normally accepted to this program. Management engineering students may be required to complete up to one year of undergraduate civil engineering courses before working on the M.S.

For the M.E.

A B.S. degree in civil engineering (or another acceptable engineering field) is required for admission to the M.E. program in civil engineering.

For the Ph.D.

Ph.D. applicants must have earned a bachelor's or master's degree. Applicants will be evaluated based on their academic background, professional experience, and other supporting application material. As the dissertation is a significant part of the Ph.D., applicants are encouraged, prior to submitting an application, to make contact with CEE faculty performing research in the area the applicant wishes to pursue.

Degree Requirements

For the M.S.

The completion of 30 semester hours of credit, of which 6 credits must be research or project work, is required. A non-thesis alternative consisting of 33 semester hours is also available. In addition to civil and environmental engineering courses, students also may take courses relevant to their major area from other departments. Students who do not have the appropriate undergraduate background for the graduate courses in their program may be required to supplement the 30 semester hours with additional undergraduate studies.

For the M.E.

The master of engineering degree requires the completion of an integrated program of study that is formulated with a CEE faculty advisor at the start of the course of study. The program and subsequent modifications thereof must be submitted to and approved by the CEE department head or the Graduate Program Coordinator, when they are developed or changed. The program requires the completion of 30 semester hours of credit. The following activities must be fulfilled through completion of the courses noted or by appropriate documentation by the department head or graduate program coordinator: experience with complex project management (CE 593 Advanced Project), competence in integration of computer applications and information technology (CE 587 Building Information Modeling), and knowledge in the area of professional business practices and ethics (CE 501 Professional Practice). The program shall also include coursework in at least two subfields of civil and environmental engineering that are related to the M.E. area of specialization.

The primary subfield will provide the student with competence required for the analysis of problems encountered in practice and the design of engineering processes, systems and facilities. Subfields are currently available in structural engineering, engineering and construction management, highway and transportation engineering, geotechnical engineering, materials engineering, geohydrology, water quality management, water resources, waste management, and impact engineering. The sub-field requirements are satisfied by completing two thematically related graduate courses that have been agreed upon by both the student and the advisor as appropriate to the program of study. In addition to the subfields noted above, other appropriate areas may be identified as long as it is clear that the courses represent advanced work and complement the program. Coursework and other academic experiences to fulfill this requirement will be defined in the integrated Plan of Study at the start of the program.

Transfer between M.S. and M.E. Program

A student may transfer from the M.E. program to the M.S. program at any time. A student may transfer from the M.S. program to the M.E. program only after an integrated program of study has been agreed upon by the student and the advisor in the area of concentration and approved by the CEE department head or the Graduate Program Coordinator.

For the Ph.D.

Doctoral students must satisfactorily complete a qualifying examination administered within the first 18 credits of admission into the Ph.D. program. The purpose of the qualifying examination is to assess the student's ability to succeed at the Ph.D. level and also to identify strengths and weaknesses in order to plan an appropriate sequence of courses. The exam is administered by a four member committee consisting of the major advisor and three other members selected by the major advisor.

In addition to the university requirements for the Ph.D. degree, the CEE department requires students to establish a minor and to pass a comprehensive examination.

Students must establish a minor outside their major area. This may be accomplished with three courses in the approved minor area. One member of the student's dissertation committee should represent the minor area. The student's dissertation committee has the authority to make decisions on academic matters associated with the Ph.D. program. To become a candidate for the doctorate, the student must pass a comprehensive examination administered by the student's dissertation committee. The candidate, on completion and submission of the dissertation, must defend it to the satisfaction of the dissertation committee.

Civil and Environmental Engineering Laboratories

The department has five civil and environmental engineering laboratories (Environmental Lab, Geotechnical Lab, Materials/Structural Lab, Structural Impact Lab and Pavement Engineering Lab), plus three computer laboratories located within Kaven Hall. The CEE laboratories are used by all civil and environmental engineering students and faculty. The computer laboratories are open to all WPI students and faculty. Uses for all laboratories include formal classes, student projects, research projects and unsupervised student activities.

Computer Laboratories

The CEE Department has a number of computer laboratories that are located in Kaven Hall and connected to WPI's network. The computer laboratories contain up-to-date computers, network connections, and presentation systems. They are used for courses, group project work and research.

Fuller Environmental Laboratory

The Fuller Laboratory is designed for state-of-the-art environmental analyses, including water and wastewater testing and treatability studies. Major equipment includes an inductively coupled plasma mass spectrometer, total organic carbon analyzer, UV-Vis spectrophotometer, particle counter, an ion chromatograph, and two gas chromatographs. Along with ancillary equipment (such as a centrifuge, autoclave, incubators, balances, pH meters and water purification system), the laboratory is equipped for a broad range of physical, chemical and biological testing. The laboratory is shared by graduate research projects, graduate and undergraduate courses (e.g. CE 4060 Environmental Engineering Laboratory) and undergraduate projects.

Geo/Water Resources Laboratory

The geo-water resources laboratory is a flexible teaching and research space that provides support for research, undergraduate and graduate projects, and courses in the areas of geotechnical engineering and water resources. The laboratory provides bench-top laboratory space for completing soil and water quality analyses, a flexible area for working with larger lab configurations that cannot be placed on the bench-top, space for preparing equipment and supplies for field investigations, and a secure area for testing, developing, and storing both field and laboratory equipment. Laboratory equipment includes fully automated stress-path-control triaxial testing system, flexible wall permeameter, and other devices for determining basic soil properties, and an aquarium and variety of tanks for demonstrating and testing equipment in water. Field equipment includes flowmeters, pumps for groundwater sampling, multiparameter water quality monitoring, and a variety of equipment for hydrologic monitoring and water quality testing.

Materials/Structural Laboratory

The Materials/Structural Laboratory is set up for materials and structures testing. The laboratory is utilized for undergraduate teaching and projects, and graduate research. The laboratory is equipped for research activities including construction materials processing and testing. Materials tested in this lab include portland cement, concrete, asphalt, and fiber composites. The laboratory has several large-load mechanical testing machines.

Pavement Research Laboratory

The pavement research laboratory provides support for graduate research and courses. The state of the art array of equipment includes compactor, moisture susceptibility testing equipment, loaded wheel tester and extraction and recovery equipment. The laboratory contains some of the most advanced testing equipment – most notable of these are the material testing system, the Model Mobile Load Simulator, and an array of Non Destructive Testing equipment consisting of the Portable Seismic Property Analyzer, Falling Weight Deflectometer and Ground Penetrating Radar. A major focus of the pavement engineering program is on the integration of undergraduate and graduate curriculum with research projects funded by the Maine Department of Transportation, Federal Highway Administration, New England Transportation Consortium and National Science Foundation.

Structural Mechanics Impact Laboratory

The Structural Mechanics Impact Laboratory is a teaching and research laboratory. The impact laboratory is used to explore the behavior of materials and components in collisions.

The Structural Mechanics Impact Laboratory consists of the following major pieces of equipment:

- An Instron Dynatup Model 8250 Instrumented Impact Test System,
- A high-speed video camera system,
- A data acquisition system,
- A large-mass drop tower,
- A space control desk, and
- National Instrument Lab View.

Course Descriptions

All courses are 3 credits unless otherwise noted.

CE 501. Professional Practice

Professional practices in engineering. Legal issues of business organizations, contracts and liability; business practice of staffing, fee structures, accounts receivable, negotiation and dispute resolution, and loss prevention; marketing and proposal development; project management involving organizing and staffing, budgeting, scheduling, performance and monitoring, and presentation of deliverables; professionalism, ethics and responsibilities.

CE 510. Structural Mechanics

Analysis of structural components: uniform and nonuniform torsion of structural shapes, analysis of determinate and indeterminate beams (including elastic foundation conditions) by classical methods, finite difference equations, numerical integrations, series approximation, elastic stability of beams and frames, lateral stability of beams, beams-columns, analysis of frames including the effect of axial compression.

Return to Table of Contents

CE 511. Structural Dynamics

Analysis and design of beams and frames under dynamic loads; dynamics of continuous beams, multistory building frames, floor systems and bridges; dynamic analysis and design of structures subjected to wind and earthquake loads; approximate methods of analysis and practical design applications.

CE 514/ME 5383. Continuum Mechanics

(2 credits)

This course covers the fundamentals of continuum mechanics at an introductory graduate level. Topics covered include: 1) Introduction: essential mathematics - scalars, vectors, tensors, and indicial notation; 2) Basics: three-dimensional states of stress, finite and infinitesimal measures strain, and principal axes; 3) Conservations laws: mass, linear momentum, angular momentum and energy; 4) Constitutive equations: ideal materials, Newtonian fluids, isotropy and anisotropy, elasticity and thermoelasticity, plasticity, and viscoelasticity; 5) Applications to classical problems and emerging topics in solid and fluid mechanics. Recommended background: undergraduate knowledge of strength of materials, fluid mechanics, and linear algebra.

CE 519. Advanced Structural Analysis

Energy methods in structural analysis, concepts of force method and displacement methods, methods of relaxation and numerical techniques for the solution of problems in buildings, and long-span structures and aircraft structural systems. Effects of secondary stress in structures. Course may be offered by special arrangement. (Prerequisites: Structural mechanics and undergraduate courses in structural analysis, differential equations.)

CE 524. Finite Element Method and Applications

This course serves as an introduction to the basic theory of the finite element method. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium problem. Examples focus on elasticity and heat flow with reference to broader applications. Students are supplied microcomputer programs and gain experience in solving real problems. Prerequisites: Elementary differential equations, solid mechanics and heat flow. Note: Students cannot receive credit for both this course and CE/ME 5303 Applied Finite Element Methods.

CE/ME 5303. Applied Finite Element Methods in Engineering

(2 credits)

This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite element methods are introduced and developed in a logical progression of complexity. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium and transient problems. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class. Students cannot receive credit for this course if they have taken the Special Topics (ME 593E) version of the same course or ME 533 or CE 524.

CE 531. Advanced Design of Steel Structures

Advanced design of steel members and connections; ultimate strength design in structural steel; codes and specifications; loads and working stresses; economic proportions; and buckling of slender elements and built-up sections, torsion, lateral-torsional buckling, beam-columns, design for lateral forces, and connections for building frames.

CE 532. Advanced Design of Reinforced Concrete Structures

Advanced design of reinforced concrete members and structural systems; effect of continuity; codes and specifications; ultimate strength theory of design; economic proportions and constructibility considerations; and deep beams, torsion, beam-columns, two-way slabs, design for lateral forces, and beam-to-column joints.

CE 534. Structural Design for Fire Conditions

The development of structural analysis and design methods for steel and reinforced concrete members subjected to elevated temperatures caused by building fires. Beams, columns and rigid frames will be covered. The course is based on research conducted during the past three decades in Europe, Canada and the United States. Course may be offered by special arrangement. (Prerequisites: Knowledge of statically indeterminate structural analysis, structural steel design and reinforced concrete design.)

CE 535. Integration of Design and Construction

As an interactive case study of the project development process, student groups design a facility and prepare a construction plan, including cost and schedule, to build the project. The students present their design-build proposal to participating industrial clients. Emphasis is on developing skills to generate, evaluate and select design alternatives that satisfy the needs of the owner and the constraints imposed by codes and regulations, as well as by the availability of construction resources. Emphasis is also in developing team-building skills and efficient communication. Computer-based methods for design, construction cost estimating and scheduling, and personal communications are extensively used. The interactive case study is specifically chosen to balance the content between design, construction engineering and management. Students taking this course are expected to have a background in at least two of these disciplines.

CE 536. Construction Failures: Analysis and Lessons

This course develops an understanding of the integration process of technical, human, capital, social and institutional aspects that drive the life cycle of a construction project. The study of failures provides an excellent vehicle to find ways for the improvement of planning, design and construction of facilities. Student groups are required to complete a term project on the investigation of a failure and present their findings and recommendations. This investigation includes not only the technical analysis of the failure but also requires a comprehensive analysis of the organizational, contractual and regulatory aspects of the process that lead to the failure. The course uses case studies to illustrate different types of failure in the planning, design, construction and operation of constructed facilities. Students taking this course are expected to have a sound academic or practical background in the disciplines mentioned above.

CE 538. Pavement Analysis and Design for Highways and Airports

This course is designed for civil engineers and provides a detailed survey of analysis and design concepts for flexible and rigid pavements for highways and airports. The material covers elastic and inelastic theories of stress pavement components and currently used design methods, i.e., Corps of Engineers, AASHTO, etc. The use of finite element methods for pavement stress and deformation analysis are presented. A review of pavement rehabilitation methods and processes is presented. (Prerequisites: differential equations, construction materials, soil mechanics, computer literacy.)

CE 542. Geohydrology

This course addresses engineering problems associated with the migration and use of subsurface water. An emphasis is placed on the geology of water-bearing formations including the study of pertinent physical and chemical characteristics of soil and rock aquifers. Topics include principles of groundwater movement, geology of groundwater occurrence, regional groundwater flow, subsurface characterization, water well technologies, groundwater chemistry and unsaturated flow.

CE 560. Advanced Principles of Water Treatment

Theory and practice of drinking water treatment. Water quality and regulations; physical and chemical unit processes including disinfection, coagulation, clarification, filtration, membranes, air stripping, adsorption, softening, corrosion control, and other advanced processes.

CE 561. Advanced Principles of Wastewater Treatment

Theory and practice of wastewater treatment. Natural purification of streams; screening; sedimentation; flotation, thickening; aerobic treatment methods; theory of aeration; anaerobic digestion; disposal methods of sludge including vacuum filtration, centrifugation and drying beds; wet oxidation; removal of phosphate and nitrogen compounds; and tertiary treatment methods.

CE 562. Biosystems in Environmental Engineering

Application of microbial and biochemical understanding to river and lake pollution; natural purification processes; biological conversion of important elements such as C, N, S, O and P; biological aspects of wastewater treatment; disease-producing organisms with emphasis on water-borne diseases; and quantitative methods used in indicator organism counts and disinfection.

CE 5621. Open Channel Hydraulics

This course begins with fundamentals of free surface flow, and includes engineering and environmental applications. Development of basic principles, including specific energy, momentum and critical flow. Rapidly varied, uniform and gradually varied steady flow phenomena and analysis. Density-stratified flow. Similitude considerations for hydraulic models. Optional topics: dispersion and heat transfer to atmosphere. Course may be offered by special arrangement.

CE 563. Industrial Waste Treatment

Legislation; the magnitude of industrial wastes; effects on streams, sewers and treatment units; physical, chemical and biological characteristics; pretreatment methods; physical treatment methods; chemical treatment methods; biological treatment methods; and wastes from specific industries. Lab includes characterization and treatment of typical industrial wastes.

CE 565. Surface Water Quality Modeling

This course provides a quantitative analysis of the fate and transport of contaminants in surface water systems. Water quality models are developed using a mass balance approach to describe the transport, dispersal, and chemical/biological reactions of substances introduced into river and lake systems. Topics covered include water quality standards, model formulation and application, waste load allocation, and water quality parameters such as biochemical oxygen demand, dissolved oxygen, nutrients, and toxic chemicals.

CE 566. Groundwater Flow and Pollution

This course provides a review of the basic principles governing ground water flow and solute transport, and examines the models available for prediction and analysis including computer models. Topics covered include mechanics of flow in porous media; development of the equations of motion and of conservation of solute mass; analytical solutions; and computer-based numerical approaches and application to seepage, well analysis, artificial recharge, groundwater pollution, salinity intrusion and regional groundwater analyses.

CE 567. Hazardous Waste: Containment, Treatment and Prevention

This course provides a survey of the areas associated with hazardous waste management. The course materials deal with identification of hazardous waste legislation, containment, storage, transport, treatment and other hazardous wastes management issues. Topics include hazardous movement and containment strategies, barrier design considerations, hazardous waste risk assessment, spill response and clean-up technologies, centralized treatment facilities, on-site treatment, in situ treatment, and industrial management and control measures. Design of selected containment and treatment systems, and a number of industrial case studies are also covered. This course is offered to students with varying backgrounds. Students interested in taking this course must identify a specific problem that deals with either regulation, containment of hazardous waste, treatment of hazardous waste or industrial source reduction of hazardous waste. This problem becomes the focal point for in-depth study. The arrangement of topics between the students and the instructor must be established by the third week. A knowledge of basic chemistry is assumed.

CE 570. Contaminant Fate and Transport

This course introduces the concepts of contaminant fate and transport processes in the environment, with consideration to exchanges across phase boundaries and the effects of reactions on environmental transport. Topics include equilibrium conditions at environmental interfaces, partitioning and distribution of contaminants in the environment, transport and exchange processes in surface water; dispersion, sorption, and the movement of non-aqueous phase liquids in ground-water, and local, urban and regional scale transport processes in the atmosphere.

CE 571. Water Chemistry

This course covers the topics of chemical equilibrium, acid/base chemistry, the carbonate system, solubility of metals, complexation and oxidation-reduction reactions. These principles will be applied to understanding of the chemistry of surface waters and groundwaters, and to understanding the behavior of chemical processes used in water and wastewater treatment.

CE 572. Physical and Chemical Treatment Processes

This course presents the physical and chemical principles for the treatment of dissolved and particulate contaminants in water and wastewater. These concepts will provide an understanding of the design of commonly used unit operations in treatment systems. Applications will be discussed as well. Topics covered include water characteristics, reactor dynamics, filtration, coagulation/flocculation, sedimentation, adsorption, gas stripping, disinfection, and chemical oxidation.

CE 573. Treatment System Hydraulics

Hydraulic principles of water, domestic wastewater and industrial wastewater systems. Hydraulic analysis and design of collection, distribution and treatment systems and equipment. Topics covered include pipe and channel flow, pump characteristics and selection, friction loss, corrosion and material selection.

CE 574. Water Resources Management

This course provides an introduction to water resources engineering and management, with an emphasis on water resources protection and water supply. Course content addresses technical aspects as well as the legal, regulatory and policy aspects of water resources management. Topics include surface water hydrology and watershed protection, development of water supplies, conjunctive use of groundwater and surface water, management of reservoirs and rivers, the role of probability and statistics, systems analysis techniques, and planning of water resources projects.

CE 580. Advanced Project Management

This course develops an understanding of the managerial principles and techniques used throughout a construction project as they are applied to its planning, preconstruction and construction phases. The course emphasizes the integrative challenges of the human, physical and capital resources as experienced from the owner's point of view in the preconstruction phase of a project. Through assignments and case studies, the course reviews the complex environment of the construction industry and processes, project costing and economic evaluation, project organization, value engineering, time scheduling, contracting and risk allocation alternatives, contract administration, and cost and time control techniques. (Prerequisites: CE 3020, CE 3025, or equivalent.)

CE 582. Engineering and Construction Information Systems

This course provides an understanding of the various subjects involved in the use, design, development, implementation and maintenance of computer- based information systems in the construction industry. Theoretical and hands-on review of basic building blocks of information and decision support systems including user interfaces, database management systems, object-oriented approaches and multimedia. Applications include project scheduling and cost control, budgeting, project risk analysis, construction accounting, materials management and procurement systems, project document tracking and resource management. Commercial software—such as PRIMAVERA Project Planner, TIMBERLINE, and spreadsheets and databases—is extensively used. Students are required to complete a term project reviewing an existing information system and presenting recommendations for improvement. (Prerequisites: A knowledge of the material covered in CE 580 and CE 584 is expected). Course may be offered by special arrangement.

CE 583. Contracts and Law for Civil Engineers

An introduction to the legal aspects of construction project management, emphasis on legal problems directly applied to the practice of project management, contracts and specifications documents, codes and zoning laws, and labor laws.

CE 584. Advanced Cost Estimating Procedures

This course examines cost estimating as a key process in planning, designing and constructing buildings. Topics include the analysis of the elements of cost estimating; database development and management, productivity, unit costs, quantity surveys and pricing, and the application of these tools in business situations; marketing, sales, bidding, negotiating, value engineering, cost control, claims management and cost history. Computerization is evaluated as an enhancement to the process.

CE 586. Building Systems

This course introduces design concepts, components, materials and processes for major building projects. The topics analyze the choice of foundations, structures, building enclosures and other major building subsystems as affected by environmental and legal conditions, and market and project constraints. Consideration is given to the functional and physical interfaces among building subsystems. Emphasis is given to the processes through which design decisions are made in the evolution of a building project.

CE 587. Building Information Modeling (BIM)

This course introduces the concept of Building Information Modeling (BIM) which is a relatively new approach in planning, design, construction and operation of constructed facilities in a technologically enabled and collaborative fashion. The course reviews fundamental concepts for collaboration and integration; it also reviews technologies that support the BIM approach and provides discipline specific as well as global perspectives on BIM. The course format includes formal lectures, computer laboratory sessions, student presentations based on assigned readings and a project developed collaboratively by the students throughout the course. Guest speakers may be invited based on the topics covered and discussed in class.

Prerequisites: Basic knowledge of computers. Exposure to professional practice in any area of the Architecture / Engineering / Construction / Facilities Management (A/E/C/FM) industry is desirable. Students are not permitted to receive credit for CE 587 if they have previously received credit for CE 585 or CE 590A-BIM.

CE 590. Special Problems

(2 to 4 credits)

Individual investigations or studies of any phase of civil engineering as may be selected by the student and approved by the faculty member who supervises the work.

CE 591. Environmental Engineering Seminar

Participation of students in discussing topics of interest to environmental engineers.

CE 592. Constructed Facilities Seminar

Participation of students, faculty and recognized experts outside of WPI in developing modern and advanced topics of interest in the constructed facilities area.

CE 593. Advanced Project

This capstone project is intended for students completing the M.E. degree. The student is expected to identify all aspects of the M.E. curriculum and an integrative, descriptive systems approach. The project activity requires the student to describe the development, design construction, maintenance and operation process for an actual facility; to evaluate the performance of the facility with respect to functional and operational objectives; and to examine alternative solutions. Specific areas of study are selected by the student and approved by the faculty member. The work may be accomplished by individuals or small groups of students working on the same project. (Prerequisite: consent of instructor.)

CE 599. M.S. Thesis

Research study at the M.S. level.

CE 699. Ph.D. Thesis

Research study at the Ph.D. level.

Return to Table of Contents

Computer Science

www.cs.wpi.edu

Faculty

C. E. Wills, Professor and Department Head; Ph.D., Purdue, 1988. Distributed systems, networking, user interfaces.

E. O. Agu, Professor; Ph.D., Massachusetts, 2001. Computer graphics, wireless networking, mobile computing and mobile health.

J. E. Beck, Associate Professor; Ph.D., Massachusetts, 2001. Machine learning, educational data mining, intelligent tutoring systems, human learning and problem solving.

D. C. Brown, Professor; Ph.D., Ohio State, 1984. Knowledge-based design systems, artificial intelligence.

M. L. Claypool, Professor; Ph.D., Minnesota, 1997. Distributed systems, networking, multimedia and online games.

L. De Carli, Assistant Professor; Ph.D., University of Wisconsin-Madison, 2016. Network Security, Web and Cloud Security, Threat Analysis and Detection.

D. J. Dougherty, Professor; Ph.D., Maryland, 1982. Logic in computer science, with a focus on security.

M. Y. Eltabakh, Associate Professor; Ph.D., Purdue University, 2010. Database management systems, information management.

L. Fichera, Assistant Professor; Ph.D., University of Genoa/Italian Institute of Technology, 2015. Computer- and robot-assisted surgery, continuum medical robots, machine learning.

M. A. Gennert, Professor; Sc.D., Massachusetts Institute of Technology, 1987. Image processing; image understanding; artificial intelligence; robotics.

T. Guo, Assistant Professor; Ph.D., University of Massachusetts Amherst, 2016. Distributed systems, cloud computing, data-intensive systems.

J. D. Guttman, Research Professor; Ph.D., Chicago, 1984. Information security, logic and formal methods, mechanized reasoning, programming languages.

L. Harrison, Assistant Professor; Ph.D., University of North Carolina at Charlotte, 2013. Information visualization, visual analytics, perception-based computation for visualization.

N. T. Heffernan, Professor; Ph.D., Carnegie Mellon, 2001. Intelligent tutoring agents, artificial intelligence, cognitive modeling, machine learning.

G. T. Heineman, Associate Professor; Ph.D., Columbia, 1996. Component-based software engineering, formal approaches to compositional design, design of algorithms.

X. Kong, Associate Professor, Ph.D., University of Illinois, Chicago, IL 2014. Data mining, social networks, machine learning, big data analytics.

D. Korkin, Professor, Ph.D., University of New Brunswick, Canada, 2003. Bioinformatics of disease, big data in biomedicine, computational genomics, systems biology, data mining, machine learning.

K. Lee, Associate Professor; Ph.D., Texas A&M, 2013, Big data analytics and mining, social computing, and cybersecurity over large-scale networked information systems such as the Web, social media and crowd-based systems.

Y. Li, Assistant Professor, Ph.D., University of Minnesota, 2003. Big data from complex networks, large-scale network data measurement, online social behavior modeling, spectral graph theory.

C. Pinciroli, Assistant Professor, PhD., Université Libre de Bruxelles, Belgium, 2014. Swarm robotics, software engineering, multi-agent systems, human-swarm interaction, programming languages.

D. Reichman, Assistant Professor; Ph.D., Weizmann Institute, 2014. Algorithms, Machine Learning, Artificial Intelligence.

C. Roberts, Assistant Professor; Ph.D., University of California at Santa Barbara, 2014. Interactive programming, audiovisual performance, music programming languages, human-centered computing.

C. Ruiz, Professor; Ph.D., Maryland, 1996. Data mining, knowledge discovery in databases, machine learning.

E. A. Rundensteiner, Professor; Ph.D., University of California, Irvine, 1992. Data and information management, big data analytics, visual analytics, machine learning.

G. N. Sarkozy, Professor; Ph.D., Rutgers, 1994. Graph theory, combinatorics, algorithms.

C. A. Shue, Associate Professor; Ph.D., Indiana, 2009. Computer networking, security, distributed systems.

C. L. Sidner, Research Professor; Ph.D., Massachusetts Institute of Technology, 1979. Discourse processing, collaboration, human-robot interaction, intelligent user interfaces, natural language processing, artificial intelligence.

G. M. Smith, Associate Professor; Ph.D., UC Santa Cruz, 2012. Computational creativity, game design, computer science education, computational craft.

E. T. Solovey, Assistant Professor; Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.

R. J. Walls, Assistant Professor; Ph.D., University of Massachusetts Amherst, 2014. Systems security and privacy, digital forensics and online crime, large-scale internet measurement.

J. R. Whitehill, Assistant Professor; Ph.D., University of California, San Diego, 2012. Machine learning, crowdsourcing, automated teaching, human behavior recognition.

J. Xiao, Professor; Ph.D., University of Michigan, 1990. Robotic manipulation and motion planning, artificial intelligence, haptics, multi-modal perception.

Return to Table of Contents

Research Interests

The current departmental activities include, among other areas, analysis of algorithms, applied logic, artificial intelligence, big data, computer vision, computer graphics, database and information systems, data mining, distributed systems, graph theory and computational complexity, intelligent tutoring systems, machine learning, network performance evaluation, programming languages, robotics, security, software engineering, user interfaces, virtual reality, visualization, and Web-based systems. Research groups meet weekly and focus on topics related to the above areas. Students are encouraged to participate in the meetings related to their area(s) of interest. Research and development projects and theses are available in these areas. Computer science students may also participate in computer applications research work being conducted in a number of other departments including electrical and computer engineering, mechanical engineering, biomedical and fire protection engineering. Students are also encouraged to undertake projects and theses in cooperation with neighboring computer manufacturers or commercial organizations.

Programs of Study

Graduate programs in Computer Science provide opportunities for advanced coursework and research for highly qualified students. Graduate Certificates, recognizing completion of a cohesive set of advanced courses, are offered in several areas of Computer Science. The Master of Science degree is more comprehensive; with thesis and non-thesis (coursework-only) options, it is the degree of choice for many full-time students and working professionals. The Doctor of Philosophy degree emphasizes deeper study and discovery in preparation for a career in research or education.

Graduate programs may be undertaken on a full-time or part-time basis. For all students, challenging courses and demanding research projects, with high expectations of accomplishment, are the standard.

Admission Requirements

Applicants are expected to demonstrate sufficient background in core Computer Science for graduate-level work. Background in both theoretical and applied Computer Science, with significant programming experience and some college-level mathematics, is required. A bachelor's degree in Computer Science or a closely related field should be adequate preparation. Students from other backgrounds are welcome to apply if they can demonstrate their readiness through other means, such as the Computer Science GRE Subject exam. Work experience will be considered if it covers a broad spectrum of Computer Science at a technical or mathematical level.

A student may apply to the Ph.D. program upon completion of either a bachelor's (*in which case the master's degree must first be completed as part of the Ph.D. studies*) or master's degree in computer science, or with an equivalent background.

Non-matriculated students may enroll in up to two courses prior to applying for admission to a Computer Science Graduate Program.

Certificate Programs

WPI's Graduate Certificate Program provides an opportunity for students holding undergraduate degrees to continue their study in an advanced area. A B.S. or B.A. degree is the general requirement. Certificate programs require a student to complete 4-5 thematically related courses in their area of interest. Each student's program of study must be approved by the academic advisor. Academic advisors are assigned upon admission to the program but may be changed in accordance with departmental policies.

Details about the certificates available in the Department of Computer Science can be found online at https://www.wpi.edu/academics/study/computer-science-certificate

Degree Requirements

For the M.S.

The M.S. program in Computer Science requires 33 credit hours of work. Students may select a non-thesis option or a thesis-option, which requires a 9-credit thesis. Each student should carefully weigh the pros and cons of these alternatives in consultation with his or her advisor prior to selecting an option, typically in the second year of study. The department will allow a student to change options only once. All entering students must submit a plan of study identifying the courses to be taken. The plan of study must be approved by the student's advisor and the CS Graduate Coordinator, and must include the following minimum requirements:

1. Computer Science Breadth Requirement (12 credits)

M.S. students are required to achieve a passing grade in courses from four different bins, including at least three essential bins. The eleven bins are listed below, together with their corresponding courses.

Essential Bins (9 credits)

- **Theory** (3 credits): 5003, 503, 521, 559
- **Algorithms** (3 credits): 5084, 584, 504
- One course from either Bin: (3 credits)
  - **Systems**: 502, 533, 535
  - **Networks**: 513, 528, 529, 530, 577, 558

Breadth Bins (3 credits)

- **Design**: 509, 546, 562
- **Compilers/Languages**: 536, 544
- **Graphics/Imaging**: 543, 545, 549, 563, 573
- **AI**: 534, 538, 539, 540, 541, 548, 549, 566
- **Databases**: 542, 561, 585, 586
- **Cybersecurity**: 557, 558, 564, 571, 578, 673
- **Applications of CS**: 526, 565, 567, 568, 582, 583

Courses with a 5000 number (e.g., 5003, 5084) are preparatory courses, designed specifically for students with insufficient background knowledge or skills. Graduate credit can be earned for these course and M.S. students may use them to satisfy bin requirements. However, students with a solid undergraduate degree in CS are strongly encouraged to take more advanced courses within the bins. *Note: B.S./M.S. students may satisfy this breadth requirement with fewer than 12 credits because of the credit conversion rate as described on page 21.*

2. Computer Science Electives (21 credits)

M.S. students must complete sufficient course work selected from CS courses at the 500-level or independent study. With the permission of the academic advisor, a student may take a total of at most six graduate credits from outside of Computer Science towards the M.S. degree. Courses in college teaching may not be counted towards the 33 credits required for a CS Master's degree.

Thesis Option

A thesis consisting of a research or development project worth a minimum of 9 credit hours must be completed and presented to the faculty. A thesis proposal must be approved by the department by the end of the semester in which a student has registered for a third thesis credit. Proposals will be considered only at regularly scheduled department meetings.

Students funded by a teaching assistant-ship, research assistantship or fellowship must complete the thesis option.

Non-thesis Option

A total of at least 33 credit hours must be satisfactorily completed, including four courses which satisfy the Breadth Requirement. Students should endeavor to take these four courses as early as possible so as to provide the background for the remaining graduate work.

Non-thesis option is not applicable to students funded by a teaching assistantship, research assistantship or fellowship.

For the Ph.D.

Students are advised to contact the department for detailed rules, as there are departmental guidelines, in addition to the university's requirements, for the Ph.D. degree.

Upon admission, the student is assigned an academic advisor and together they design a Plan of Study during the first semester of the student's Ph.D. program.

The student must satisfy the Ph.D. Qualifying Requirement, consisting of the Breadth Requirement and the Research Qualifying Requirement. These requirements are described in the Graduate Regulations on the CS department website https://web.cs.wpi.edu/Intranet/Graduate/guide.html.

Upon successful completion of the Ph.D. qualifying requirement, the student becomes a computer science Ph.D. candidate. The student's Dissertation Committee must be formed within the first year of candidacy. The student selects a research advisor from within the CS department, and together they select, with the approval of the CS Graduate Committee, three additional members, at least one of whom must be from outside the WPI CS department. The Dissertation Committee will be responsible for supervising the comprehensive examination, and approving the dissertation proposal and final report.

The Ph.D. degree requirements consist of a coursework component and a research component, which together must total at least 60 credit hours beyond the master's degree requirement for Ph.D. students who earned a MS degree in a program other than CS at WPI. The coursework and research component must total at least 57 credit hours for students who earn both a master's degree and Ph.D. degree in CS at WPI. The coursework component must include 1) the completion of the student's Ph.D. Breadth Requirements and 2) 15 graduate credits in Computer Science courses, independent studies, or directed research (these 15 credits may include credits earned as part of completing the Ph.D. Breadth Requirements). Coursework credits taken outside Computer Science must be approved by the student's advisor.

The student may also enroll for research credits, but is only allowed up to 18 directed research credits prior to the completion of the Ph.D. candidacy requirements. The Ph.D. candidacy requirements are the completion of the Ph.D. Breadth Requirements and the Ph.D. Research Qualifier. With the approval of the Dissertation Committee, the student applies for and takes the Ph.D. comprehensive examination. This examination must be passed prior to the completion of the dissertation defense and is normally taken after some initial dissertation research has been performed. With approval of the Dissertation Committee, the student applies for and takes the dissertation proposal examination, usually within one year of the Ph.D. candidacy.

The Ph.D. research component consists of at least 30 credits (including any research credits earned prior to the acceptance of the dissertation proposal and excluding any research credits applied toward a master's degree) leading to a dissertation and a public defense, which must be approved by the student's Dissertation Committee.

Ph.D. Breadth Requirements

Ph.D. students are required to achieve at least a B grade in courses from six different bins (listed earlier in the CS Breadth Requirement for the M.S. Degree). These six bins must include all three essential bins. Students must achieve an A grade in at least four of the six bins, including an A grade in at least one essential bin.

Courses with a 5000 number (e.g., 5003, 5084) are "preparatory courses", designed specifically for students with insufficient background knowledge or skills. While graduate credit can be earned for these courses, they cannot be used by Ph.D. students to satisfy a bin requirement.

The Ph.D. breadth requirement must be satisfied by the time the student achieves the following number of graduate credits: for PhD-90: 54 credits (18 courses); for PhD-60: 36 credits (12 courses).

Students admitted to the CS Ph.D. program with only a bachelor's degree (i.e., PhD-90) must complete a CS MS degree as the first step towards the Ph.D. However, the Ph.D. breadth requirement is more demanding than the MS breadth requirement. Consequently, those students should satisfy the Ph.D. breadth requirement instead while obtaining the MS degree. All other requirements for the M.S. degree remain the same.

B.S./M.S. Program

Overview

The university rules for the B.S./M.S. program are described in Section 5 of the undergraduate catalog and on page 21 of the graduate catalog.

Process

Students may formally apply for admission to the B.S./M.S. program during or after taking their second 4000-level Computer Science course. Forms are available through the graduate admissions office or via their website.

Students who have entered the B.S./M.S. program, or are considering it, qualify for B.S./M.S. credit for the courses listed below.

In order to receive graduate credits for a 4000-level course, the student must earn a B course grade or higher. Course instructors may waive the course grade requirement at their discretion. Faculty may offer, at their discretion, an additional 1/6 undergraduate unit, or equivalently a 1 graduate credit, for completing additional work in the course. To obtain this credit, the student must register for 1/6 undergraduate unit of independent study at the 4000-level or a 1 graduate credit independent study at the 500-level, with permission from the instructor..

Regulations

The CS department allows only selected 4000-level undergraduate course credits to count towards the B.S./M.S. The CS 4000-level course credits that may be counted towards both degrees are:

- 4100, 4120, 4123, 4233, 4241, 4341, 4401, 4404, 4432, 4445, 4513, 4515, 4516, 4518, 4533, 4536, 4731, 4732, 4802, 4803
- 4000-level Undergraduate Independent Studies, with permission of instructor and either the Graduate Committee or the Department Chair

Some undergraduate and graduate courses cover similar material. Students may receive credit for both when the graduate course covers extensive material beyond the undergraduate course. The table below lists courses with significant overlap. A student can receive credit for at most one of the two courses in any row of this table.

Undergraduate Course	Graduate Course
CS 4341 Introduction to Artificial Intelligence	CS 534 Artificial Intelligence
CS 4342 Machine Learning	CS 539 Machine Learning
CS 4432 Database Systems II	CS 542 Database Management Systems
CS 4445 Data Mining and Knowledge Discovery in Databases	CS 548 Knowledge Discovery and Data Mining
CS 4513 Distributed Systems	CS 502 Operating Systems
CS 4516 Advanced Computer Networks	CS 513 Computer Networks
CS 4518 Mobile and Ubiquitous Computing	CS 528 Mobile and Ubiquitous Computing
CS 4533 Techniques of Programming Language Translation	CS 544 Compiler Construction
CS 4536 Programming Languages	CS 536 Programming Language Design
CS 4731 Computer Graphics	CS 543 Computer Graphics
CS 4802 Biovisualization	CS 582 Biovisualization
CS 4803 Biological and Biomedical Database Mining	CS 583 Biological and Biomedical Database Mining

A B.S./M.S. student may use 1/3 unit of undergraduate credit or independent study/project work taken for B.S./M.S. credit to satisfy a bin requirement, if any of the following conditions is met: (1) The undergraduate course covers material similar to that of a graduate course that satisfies the bin. The table above provides pairs of undergraduate and graduate courses that cover similar material. The undergraduate course under consideration must appear in this table, and the corresponding graduate course must satisfy the bin requirement. (2) The course or independent study/project work is deemed to satisfy the bin by the instructor, Bin Committee, and Graduate Program Chair as indicated on the Graduate Bins Petition Form. (3) B.S./M.S. students that receive B.S./M.S. credit for one of the following courses can use that course to satisfy the corresponding bin.

- **Theory**: 4123 (Theory of Computation)
- **Algorithms**: 4120 (Analysis of Algorithms)
- **Design**: 4233 (OOAD), 4241 (Webware)
- **Graphics/Imaging**: 4732 (Animation)
- **Cyber Security**: 4401 (Software Security), 4404 (Tools and Techniques)
- **Applications of CS**: 4100 (AI for IMGD)

Facilities

WPI boasts excellent computing resources and network connectivity through the university's Computing & Communications Center and the CS Department's own systems. A wide range of machines provides web, mail, file, high-performance computation, and security services. An extensive software library is available free of charge to all campus users. Other specialized resources include multiple high performance and parallel-computing clusters. WPI is a member of the Internet2 consortium and WPI's campus network consists of a 10 Gigabit (on campus) backbone with multiple connections to the global internet. High speed wireless connectivity is available virtually everywhere on campus.

Off-Campus Research Opportunities

Computer science graduate students have opportunities for research and development in cooperation with several neighboring organizations, both for the master's thesis and Ph.D. dissertation. These and other opportunities provide real-world problems and experiences consistent with WPI's policy of extending learning beyond the classroom.

Course Descriptions

All courses are 3 credits unless otherwise noted.

CS 5003. Foundations of Computer Science: an Introduction

This is the study of mathematical foundations of computing, at a slower pace than that of CS 503 and with correspondingly fewer background assumptions. Topics include finite automata and regular languages, pushdown automata and context-free languages, Turing machines and decidability, and an introduction to computational complexity. (Prerequisite: an undergraduate course in discrete mathematics.)

CS 5007. Introduction to Applications of Computer Science with Data Structures and Algorithms

This is an introductory graduate course teaching core computer science topics typically found in an undergraduate Computer Science curriculum, but at a graduate-level pace. It is primarily intended for students with little formal preparation in Computer Science to gain experience with fundamental Computer Science topics.

After a review of programming concepts the focus of the course will be on data structures from the point of view of the operations performed upon the data and to apply analysis and design techniques to non-numeric algorithms that act on data structures. The data structures covered include lists, stacks, queues, trees and graphs. Projects will focus on the writing of programs to appropriately integrate data structures and algorithms for a variety of applications.

This course may not be used to satisfy degree requirements for a B.S., M.S., or Ph.D. degree in Computer Science or a minor in Computer Science. It may satisfy the requirements for other degree programs at the discretion of the program review committee for the particular degree. (Prerequisites: Experience with at least one high-level programming language such as obtained in an undergraduate programming course.)

CS 502. Operating Systems

The design and theory of multiprogrammed operating systems, concurrent processes, process communication, input/output supervisors, memory management, resource allocation and scheduling are studied. (Prerequisites: knowledge of computer organization and elementary data structures, and a strong programming background.)

CS 503. Foundations of Computer Science

This is the study of mathematical foundations of computing. Topics include finite automata and regular languages, pushdown automata and context-free languages, Turing machines and decidability, and an introduction to computational complexity. (Prerequisites: Knowledge of discrete mathematics and algorithms at the undergraduate level, and some facility with reading and writing mathematical proofs.)

CS 504. Analysis of Computations and Systems

The following tools for the analysis of computer programs and systems are studied: probability, combinatorics, the solution of recurrence relations and the establishment of asymptotic bounds. A number of algorithms and advanced data structures are discussed, as well as paradigms for algorithm design. (Prerequisites: CS 5084 or equivalent.)

CS 5084. Introduction to Algorithms: Design and Analysis

This course is an introduction to the design, analysis and proofs of correctness of algorithms. Examples are drawn from algorithms for many areas. Analysis techniques include asymptotic worst case and average case, as well as amortized analysis. Average case analysis includes the development of a probability model. Techniques for proving lower bounds on complexity are discussed, along with NP-completeness. Prerequisites: an undergraduate knowledge of discrete mathematics and data structures. *Note: students with a strong background in design and analysis of computer systems, at the level equal to a B.S. in computer science, should not take CS 5084 and should consider taking CS 504 or CS 584.*

CS 509. Design of Software Systems

This course introduces students to a methodology and specific design techniques for team-based development of a software system. Against the backdrop of the software engineering life-cycle, this course focuses on the object-oriented paradigm and its supporting processes and tools. Students will be exposed to industrial-accepted standards and tools, such as requirements elicitation, specification, modeling notations, design patterns, software architecture, integrated development environments and testing frameworks. Students will be expected to work together in teams in the complete specification, implementation and testing of a software application. Prerequisites: knowledge of a recursive high-level language and data structures. An undergraduate course in software engineering is desirable.

CS 513. Computer Networks

This course provides an introduction to the theory and practice of the design of computer and communications networks, including the ISO seven-layer reference model. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types including local area and wide area networks are introduced, as are evolving network technologies. The theory, design and performance of local area networks are emphasized. The course includes an introduction to queueing analysis and network programming. (Prerequisites: knowledge of the C programming language is assumed. CS 504 or equivalent background in CS 5084 or CS 584.)

CS 514/ECE 572. Advanced Systems Architecture

See ECE 572 course description on page 104.

CS 521. Logic in Computer Science

This course is an introduction to mathematical logic from a computer science perspective. Topics covered include the exploration of model theory, proof theory, and decidability for propositional and first-order classical logics, as well as various non-classical logics that provide iseful tools for computer science (such as temporal and intuitionistic logics). The course stresses the application of logic to various areas of computer science such as computability, theorem proving, programming languages, specification,and verification. The specific applications included will vary by instructor. (Prerequisites: CS 503, or equivalent background in basic models of computation.)

CS 522/MA 510. Numerical Methods

See MA 510 course description.

CS 525. Topics in Computer Science

A topic of current interest is covered in detail. Please consult the department for a current listing of selected topics in this area. (Prerequisites: vary with topic.)

CS/RBE 526. Human-Robot Interaction

This course focuses on human-robot interaction and social robot learning, exploring the leading research, design principles and technical challenges we face in developing robots capable of operating in real-world human environments. The course will cover a range of multidisciplinary topics, including physical embodiment, mixed-initiative interaction, multi-modal interfaces, human-robot teamwork, learning algorithms, aspects of social cognition, and long-term interaction. These topics will be pursued through independent reading, class discussion, and a final project. (Prerequisites: Mature programming skills and at least undergraduate level knowledge of Artificial Intelligence, such as CS 4341. No hardware experience is required.)

CS 528. Mobile and Ubiquitous Computing

This course acquaints participants with the fundamental concepts and state-of-the-art computer science research in mobile and ubiquitous computing. Topics covered include mobile systems issues, human activity and emotion sensing, location sensing, mobile HCI, mobile social networking, mobile health, power saving techniques, energy and mobile performance measurement studies and mobile security. The course consists of weekly presentations on current advanced literature, discussions and a term project. The term project involves implementing research ideas on a mobile device such as a smartphone. (Prerequisite: CS 502 or an equivalent graduate level course in Operating Systems, and CS 513 or an equivalent graduate level course in Computer Networks, and proficiency in a high level programming language.)

Return to Table of Contents

CS 529. Multimedia Networking

This course covers basic and advanced topics related to using computers to support audio and video over a network. Topics related to multimedia will be selected from areas such as compression, network protocols, routing, operating systems and human computer interaction. Students will be expected to read assigned research papers and complete several programming intensive projects that illustrate different aspects of multimedia computing. (Prerequisites: CS 502 and CS 513 or the equivalent and strong programming skills.)

CS 533/ECE 581. Modeling and Performance Evaluation of Network and Computer Systems

Methods and concepts of computer and communication network modeling and system performance – evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service and priority systems; work load characterization; performance evaluation problems. (Prerequisites: CS 5084 or CS 504 or equivalent background in probability and some background in statistics.)

CS 534. Artificial Intelligence

This course gives a broad survey of artificial intelligence. The course will cover methods from search, probabilistic reasoning, and learning, among other topics. Selected topics involving the applications of these tools are investigated. Such topics might include natural language understanding, scene understanding, game playing, and planning. (Prerequisites: familiarity with data structures and a high-level programming language.)

CS 535. Advanced Topics in Operating Systems

This course discusses advanced topics in the theory, design and implementation of operating systems. Topics will be selected from such areas as performance of operating systems, distributed operating systems, operating systems for multiprocessor systems and operating systems research. (Prerequisites: CS 502 and either CS 5084, CS 504, CS 584, or equivalent background in probability.)

CS 536. Programming Language Design

This course discusses the fundamental concepts and general principles underlying current programming languages and models. Topics include control and data abstractions, language processing and binding, indeterminacy and delayed evaluation, and languages and models for parallel and distributed processing. A variety of computational paradigms are discussed: functional programming, logic programming, object-oriented programming and data flow programming. (Prerequisites: student is expected to know a recursive programming language and to have an undergraduate course in data structures.)

CS 538. Knowledge-Based Systems

The course will review knowledge-based problem-solving systems. It will concentrate on an analysis of their architecture, knowledge and problem-solving style in order to classify and compare them. An attempt will be made to evaluate the contribution to our understanding of problems that such systems can tackle. (Prerequisite: CS 534 or equivalent or permission of the instructor.)

CS 539. Machine Learning

The focus of this course is machine learning for knowledge-based systems. It will include reviews of work on similarity-based learning (induction), explanation-based learning, analogical and case-based reasoning and learning, and knowledge compilation. It will also consider other approaches to automated knowledge acquisition as well as connectionist learning. (Prerequisite: CS 534 or equivalent, or permission of the instructor.)

CS 540. Artificial Intelligence in Design

The main goal of this course is to obtain a deeper understanding of what “design” is, and how AI might be used to support and study it. Students will examine some of the recent AI-based work on design problem-solving. The course will be run in seminar style, with readings from the current literature and with student presentations. The domains will include electrical engineering design, mechanical engineering design, civil engineering design and software design (i.e., automatic programming). This course will be of interest to those wanting to prepare for research in design, or those wishing to increase their understanding of expert systems. Graduate students from departments other than computer science are welcome. (Prerequisite: knowledge of artificial intelligence is required. This can only be waived with permission of the instructor).

CS/DS 541. Deep Learning

This course will offer a mathematical and practical perspective on artificial neural networks for machine learning. Students will learn about the most prominent network architectures including multilayer feedforward neural networks, convolutional neural networks (CNNs), auto-encoders, recurrent neural networks (RNNs), and generative-adversarial networks (GANs). This course will also teach students optimization and regularization techniques used to train them -- such as backpropagation, stochastic gradient descent, dropout, pooling, and batch normalization. Connections to related machine learning techniques and algorithms, such as probabilistic graphical models, will be explored. In addition to understanding the mathematics behind deep learning, students will also engage in hands-on course projects. Students will have the opportunity to train neural networks for a wide range of applications, such as object detection, facial expression recognition, handwriting analysis, and natural language processing. Prerequisite: Machine Learning (CS 539), and knowledge of Linear Algebra (such as MA 2071) and Algorithms (such as CS 2223).

CS 542. Database Management Systems

An introduction to the theory and design of data-base management systems. Topics covered include internals of database management systems, fundamental concepts in database theory, and database application design and development. In particular, logical design and conceptual modeling, physical database design strategies, relational data model and query languages, query optimization, transaction management and distributed databases. Typically there are hands-on assignments and/or a course project. Selected topics from the current database research literature may be touched upon as well. (Prerequisite: CS 5084 would be helpful.)

CS 543. Computer Graphics

This course examines typical graphics systems, both hardware and software; design of low-level software support for raster displays; 3-D surface and solids modeling; hidden line and hidden surface algorithms; and realistic image rendering including shading, shadowing, reflection, refraction and surface texturing. (Prerequisites: familiarity with data structures, a recursive high-level language and linear algebra. CS 509 would be helpful.)

CS 544. Compiler Construction

A general approach to the design of language processors is presented without regard for either the source language or target machine. All phases of compilation and interpretation are investigated in order to give the student an appreciation for the overall construction of a compiler. Typical projects may include implementation of a small compiler for a recursive or special-purpose language. (Prerequisites: knowledge of several higher-level languages and at least one assembly language. The material in CS 503 is helpful.)

CS 545/ECE 545. Digital Image Processing

This course presents fundamental concepts of digital image processing and an introduction to machine vision. Image processing topics will include visual perception, image formation, imaging geometries, image transform theory and applications, enhancement, restoration, encoding and compression. Machine vision topics will include feature extraction and representation, stereo vision, model-based recognition, motion and image flow, and pattern recognition. Students will be required to complete programming assignments in a high-level language. (Prerequisites: working knowledge of undergraduate level signal analysis and linear algebra; familiarity with probability theory is helpful but not necessary.)

CS 546. Human-Computer Interaction

This course prepares graduate students for research in human-computer interaction. Topics include the design and evaluation of interactive computer systems, basic psychological considerations of interaction, interactive language design, interactive hardware design and special input/output techniques. Students are expected to present and review recent research results from the literature, and to complete several projects. (Prerequisites: students are expected to have mature programming skills. Knowledge of software engineering would be an advantage.)

CS/DS 547. Information Retrieval

This course introduces the theory, design, and implementation of text-based and Web-based information retrieval systems. Students learn the key concepts and models relevant to information retrieval and natural language processing on large-scale corpus such as the Web and social systems. Topics include vector space model, crawling, indexing, web search, ranking, recommender systems, embedding and language model. Prerequisites: statistical learning at the level of DS 502/MA 543 and programming skills at the level of CS 5007.

CS 548. Knowledge Discovery and Data Mining

This course presents current research in Knowledge Discovery in Databases (KDD) dealing with data integration, mining, and interpretation of patterns in large collections of data. Topics include data warehousing and data preprocessing techniques; data mining techniques for classification, regression, clustering, deviation detection, and association analysis; and evaluation of patterns minded from data. Industrial and scientific applications are discussed. Recommended background: Background in artificial intelligence, databases, and statistics at the undergraduate level, or permission of the instructor. Proficiency in a high level programming language.

CS/RBE 549. Computer Vision

This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images. (Prerequisites: CS 534, CS 543, CS 545, or the equivalent of one of these courses.)

CS 557. Software Security Design and Analysis

Software is responsible for enforcing many central security goals in computer systems. These goals include authenticating users and other external principals, authorizing their actions, and ensuring the integrity and confidentiality of their data. This course studies how to design, implement, and analyze mechanisms to enforce these goals in both web systems and programs in traditional languages. Topics include: identifying programming choices that lead to reliable or flawed security outcomes, successful and unsuccessful strategies for incorporating cryptography into software, and analysis techniques that identify security vulnerabilities. The course will cover both practical and theoretical aspects of secure software, and will include a substantial secure software design project. (Prerequisites: Programming and software engineering experience (commensurate with an undergraduate Computer Science major), and background in foundational models of computing systems (on par with CS 5003 or CS 503).)

CS 558. Computer Network Security

This course covers core security threats and mitigations at the network level. Topics include: denial-of-service, network capabilities, intrusion detection and prevention systems, worms, botnets, Web attacks, anonymity, honeypots, cybercrime (such as phishing), and legality and ethics. The course prepares students to think broadly and concretely about network security; it is not designed to teach students low-level tools for monitoring or maintaining system security. Assignments and projects will assess each student's ability to think both conceptually and practically about network security. (Prerequisites: a strong background in computer networking and systems, either at the undergraduate or graduate level, and moderate programming experience.)

CS 559. Advanced Topics in Theoretical Computer Science

This course has an instructor-dependent syllabus.

CS 561. Advanced Topics in Database Systems

This course covers modern database and information systems as well as research issues in the field. Topics and systems covered may include object-oriented, workflow, active, deductive, spatial, temporal and multimedia databases. Also discussed will be recent advances in database systems such as data mining, online analytical processing, data warehousing, declarative and visual query languages, multimedia database tools, web and unstructured data sources, and client-server and heterogeneous systems. The specific subset of topics for a given course offering is selected by the instructor. Research papers from recent journals and conferences are used. Group project required. (Prerequisites: CS 542 or equivalent. Expected background includes a knowledge of relational database systems.)

CS 562. Advanced Topics in Software Engineering

This course focuses on the nondesign aspects of software engineering. Topics may include requirements specification, software quality assurance, software project management and software maintenance. (Prerequisite: CS 509.)

CS 564. Advanced Topics in Computer Security

This course examines one or more selected current issues in the area of computer security. Specific topics covered are dependent on the instructor. Potential topics include: modeling and analyzing security protocols, access-control, network security, and human-centered security. (Prerequisites: a graduate level security course or equivalent experience.

CS/SEME 565. User Modeling

User modeling is a cross-disciplinary research field that attempts to construct models of human behavior within a specific computer environment. Contrary to traditional artificial intelligence research, the goal is not to imitate human behavior as such, but to make the machine able to understand the expectations, goals, knowledge, information needs, and desires of a user in terms of a specific computing environment. The computer representation of this information about a user is called a user model, and systems that construct and utilize such models are called user modeling systems. A simple example of a user model would be an e-commerce site which makes use of the user's and similar users' purchasing and browsing behavior in order to better understand the user's preferences. In this class, the focus is on obtaining a general understanding of user modeling, and an understanding of how to apply user modeling techniques. Students will read seminal papers in the user modeling literature, as well as complete a course project where students build a system that explicitly models the user. (Prerequisites: Knowledge of probability.)

CS/SEME 566. Graphical Models for Reasoning Under Uncertainty

This course will introduce students to graphical models, such as Bayesian networks, Hidden Markov Models, Kalman filters, particle filters, and structural equation models. Graphical models are applicable in a wide variety of work in computer science for reasoning under uncertainty such as user modeling, speech recognition, computer vision, object tracking, and determining a robot's location. This course will cover 1) using data to estimate the parameters and structure of a model using techniques such as expectation maximization, 2) understanding techniques for performing efficient inference on new observations such as junction trees and sampling, and 3) learning about evaluation techniques to determine whether a particular model is a good one. (Prerequisites: CS 534 Artificial Intelligence or permission of the instructor.)

CS/SEME 567. Empirical Methods for Human-Centered Computing

This course introduces students to techniques for performing rigorous empirical research in computer science. Since good empirical work depends on asking good research questions, this course will emphasize creating conceptual frameworks and using them to drive research. In addition to helping students understand what makes a good research question and why, some elementary statistics will be covered. Furthermore, students will use and implement computationally intensive techniques such as randomization, bootstrapping, and permutation tests. The course also covers experiments involving human subjects, and some of the statistical and non-statistical difficulties researchers often encounter while performing such work (e.g., IRB (Institutional Review Board), correlated trials, and small sample sizes). While this course is designed for students in Human Computer Interaction, Interactive Media & Game Development, and Learning Sciences and Technologies, it is appropriate for any student with programming experience who is doing empirical research. (Prerequisites: MA 511 Applied Statistics for Engineers and Scientists or permission of instructor.)

Return to Table of Contents

CS/SEME 568. Artificial Intelligence for Adaptive Educational Technology

Students will learn how to enable educational technology to adapt to the user and about typical architectures used by existing intelligent tutoring systems for adapting to users. Students will see applications of decision theoretic systems, reinforcement learning, Markov models for action selection, and Artificial Intelligence (AI) planning. Students will read papers that apply AI techniques for the purpose of adapting to users. Students will complete a project that applies these techniques to build an adaptive educational system. (Prerequisites: CS 534 Artificial Intelligence or permission of the instructor.)

CS 571. Case Studies in Computer Security

This course examines security challenges and failures holistically, taking into account technical concerns, human behavior, and business decisions. Using a series of detailed case studies, students will explore the interplay among these dimensions in creating secure computing systems and infrastructure. Students will also apply lessons from the case studies to emerging secure-systems design problems. The course requires active participation in class discussions, presentations, and writing assignments. It does not involve programming, but assumes that students have substantial prior experience with security protocols, attacks, and mitigations at the implementation level. This course satisfies the behavioral component of the M.S. specialization in computer security. (Prerequisites: A prior course or equivalent experience in technical aspects of computer security, at either the software or systems level.)

CS 573. Data Visualization

This course exposes students to the field of data visualization, i.e., the graphical communication of data and information for the purposes of presentation, confirmation, and exploration. The course introduces the stages of the visualization pipeline. This includes data modeling, mapping data attributes to graphical attributes, visual display techniques, tools, paradigms, and perceptual issues. Students learn to evaluate the effectiveness of visualizations for specific data, task, and user types. Students implement visualization algorithms and undertake projects involving the use of commercial and public-domain visualization tools. Students also read papers from the current visualization literature and do classroom presentations. (Prerequisite: a graduate or undergraduate course in computer graphics.)

CS 577/ECE 537. Advanced Computer and Communications Networks

This course covers advanced topics in the theory, design and performance of computer and communications networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queueing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies. (Prerequisite: CS 533/ECE 581 and either CS 513 or ECE 506)

CS 578/ECE 578. Cryptography and Data Security

See ECE 578 course description.

CS 582/BCB 502. Biovisualization

This course uses interactive visualization to explore and analyze data, structures, and processes Topics include the fundamental principles, concepts, and techniques of visualization and how visualization can be used to analyze and communicate data in domains such as biology. Students will be expected to design and implement visualizations to experiment with different visual mappings and data types, and will complete a research oriented project. Prerequisite: experience with programming (especially JavaScript), databases, and data structures. Students may not receive credit for both CS 582 and CS 4802.

CS 583/BCB 503. Biological and Biomedical Database Mining

This course will investigate computational techniques for discovering patterns in and across complex biological and biomedical sources including genomic and proteomic databases, clinical databases, digital libraries of scientific articles, and ontologies. Techniques covered will be drawn from several areas including sequence mining, statistical natural language processing and text mining, and data mining. (Prerequisite: strong programming skills, an undergraduate or graduate course in algorithms, an undergraduate course in statistics, and one or more undergraduate biology courses.) Students may not receive credit for both CS 583 and CS 4803.

CS 584. Algorithms: Design and Analysis

This covers the same material as CS5084 though at a more advanced level. As background, students should have experience writing programs in a recursive, high-level language and should have the background in mathematics that could be expected from a B.S. in Computer Science.

CS 585/DS 503. Big Data Management

Big Data Management deals with emerging applications in science and engineering disciplines that generate and collect data at unprecedented speed, scale, and complexity that need to be managed and analyzed efficiently. This course introduces the latest techniques and infrastructures developed for big data management including parallel and distributed database systems, map-reduce infrastructures, scalable platforms for complex data types, stream processing systems, and cloud-based computing. Query processing, optimization, access methods, storage layouts, and energy management techniques developed on these infrastructures will be covered. Students are expected to engage in hands-on projects using one or more of these technologies. Prerequisites: A beginning course in databases at the level of CS 4432 or equivalent knowledge, and programming experience.

CS 586/DS 504. Big Data Analytics

Big Data Analytics addresses the obstacle that innovation and discoveries are no longer hindered by the ability to collect data, but by the ability to summarize, analyze, and discover knowledge from the collected data in a scalable fashion. This course covers computational techniques and algorithms for analyzing and mining patterns in large-scale datasets. Techniques studied address data analysis issues related to data volume (scalable and distributed analysis), data velocity (high-speed data streams), data variety (complex, heterogeneous, or unstructured data), and data veracity (data uncertainty). Techniques include mining and machine learning techniques for complex data types, and scale-up and scale-out strategies that leverage big data infrastructures. Real-world applications using these techniques, for instance social media analysis and scientific data mining, are selectively discussed. Students are expected to engage in hands-on projects using one or more of these technologies. Prerequisites: A beginning course in databases and a beginning course in data mining, or equivalent knowledge, and programming experience.

CS 598. Directed Research

CS 599. Master's Thesis

CS 673/ECE 673. Advanced Cryptography

See ECE 673 course description.

CS 699. Ph.D. Dissertation

Computer Security

Program of Study

A specialization in computer security is available within the master's degree program of the Computer Science (CS) Department.

Students enrolled in this specialization will receive the master of science degree in computer science, with a notation on their transcript "Specialization in Computer Security." The program is focused on preparing students for both industrial positions and Ph.D. study related to computer security.

WPI's cyber-security programs place the science and engineering of security within the broader holistic frameworks of institutions and society. The specialization in Computer Science prepares students to approach technical computer security problems in the context of users and organizations. The M.S. specialization in computer security strives to produce students who

- can assess which security-related threats to address in a computing problem
- understand technical security vulnerabilities and technologies at least two different abstraction levels within computing systems
- appreciate behavioral and human factors in creating feasible security systems

Admission Requirements

The program is conducted at an advanced technical level and requires, in addition to the WPI admissions requirements, a solid background in computer science (CS). Normally a B.S. degree in CS is expected; however, applicants with comparable backgrounds, together with expertise gained through work experience, will also be considered. Interested students should apply to the CS master's degree program. Admission decisions are made by the CS department.

Degree Requirements

33 credits

The Computer Security specialization has both coursework-only and thesis options. The program distribution requirements are as follows:

- Security Core: 6 credits
- Security Electives: 6 credits for the coursework option, or 3 credits for the thesis option. At least one elective course must emphasize Behavioral Dimensions of security.
- Business/Management: 3 credits
- Computer Science Bins: 12 credits
- Either 6 credits of general CS electives (coursework option) or 9 credits of M.S. thesis (thesis option)

The following courses satisfy each requirement:

Security Core: Courses covering two of software, systems/networks, and wireless/internet level security. Current applicable courses are:

- CS 557 (Software Security Design and Analysis)
- CS 558 (Network Security)
- ECE 579W (Wireless and Internet Security)

Students with B.S./M.S. credit for CS 4401 (Software Security Engineering) or CS 4404 (Tools and Techniques in Computer Network Security) may apply at most one of these courses towards the security core requirement for the M.S. specialization.

Security Electives: Includes all security-related courses offered in Computer Science and Electrical and Computer Engineering. Up to three credits from thesis work on a security-related topic may count towards this requirement, with the approval of the specialization director. Current applicable courses are the security core courses as well as:

- CS 571 (Case Studies in Computer Security) [satisfies Behavioral Dimensions requirement]
- CS 578 (Cryptography)
- CS/ECE 673 (Advanced Cryptography)
- CS 564 (Advanced Topics in Computer Security)
- Special topics courses with the approval of the specialization director

At least one course counted towards security electives must provide significant coverage of behavioral dimensions of cyber security. Permanent course offerings that satisfy the behavioral dimensions requirement are designated as such in their catalog descriptions. The instructors of topics courses (CS 525 and CS 5XX) and independent study courses may designate particular offerings as satisfying the behavioral requirement with the approval of the Specialization Director.

Business/Management: Courses covering business or management issues that bear on security concerns. Current applicable courses are:

- MIS 582 (Information Security Management)
- OIE 542 (Risk Management and Decision Making)

Computer Science Bins: Courses as required to satisfy the breadth requirements ("bins") for the CS M.S. degree. Details appear in the CS M.S. degree requirements.

Electives: Any courses allowable within the requirements for CS M.S. degrees, including thesis credits.

Thesis Approval: If a student applies thesis credits towards a degree bearing the computer security specialization, his or her thesis topic must be approved as security-related by one of the core specialization faculty. Theses need not be advised by core specialization faculty; in such cases, the reader should be one of the core specialization faculty.

Important Note

Since the security specialization is within the master's programs of the Computer Science Department, students in this specialization must also satisfy all requirements of the computer science master's program. There is a limit to the number of courses outside of Computer Science that students may apply towards their Computer Science master's degree.

Return to Table of Contents

Faculty

E. A. Rundensteiner, Professor, Computer Science Department and Program Director, Data Science. Ph.D., University of California, Irvine, 1992. Big data processing, big data analytics, visual analytics, machine learning.

M. Eltabakh, Associate Professor, Computer Science Department. Ph.D., Purdue University, 2010. Database management systems and information management, query processing and optimization, indexing techniques, scientific data management, and big data analytics.

F. Emdad, Associate Teaching Professor, Data Science Program. Ph.D., Colorado State University, 2007. Business analytics, computational and applied mathematics.

L. Harrison, Assistant Professor, Computer Science Department. Ph.D., University of North Carolina, 2013. Data visualization, visual analytics, human computer interaction.

X. Kong, Associate Professor, Computer Science Department, Ph.D., University of Illinois, 2014. Data mining and big data analysis, with emphasis on addressing the data variety issues in biomedical research and social computing, and healthcare analytics.

N. Kordzadeh, Ph.D., University of Texas at San Antonio. Assistant Professor of Information Systems, Robert A. Foisie School of Business. Organizational and individual adoption and use of social media in healthcare; business intelligence and analytics with an emphasis on algorithmic fairness and ethical decision-making.

K. Lee, Associate Professor, Computer Science Department, Ph.D., Texas A&M University, 2013. Big data analytics and mining, social computing, and cybersecurity over large-scale networked information systems such as the Web, social media and crowd-based systems.

Y. Li, Assistant Professor, Computer Science Department, Ph.D., University of Minnesota, 2013. Ph.D., BUPT, Beijing, China, 2009. Data mining and artificial intelligence with applications in urban computing, smart transportation, and human mobility analysis.

O. Mangoubi, Assistant Professor, Mathematical Science Department. PhD, Massachusetts Institute of Technology, 2016. Optimization, Machine learning, Statistical algorithms.

C. Ngan, Assistant Teaching Professor, Data Science, Ph.D., George Mason University, 2013. Time Series Analysis, Decision Guidance and Support Systems.

R. C. Paffenroth, Associate Professor, Mathematical Sciences Department, Ph.D., University of Maryland, 1999. Large scale data analytics, statistical machine learning, compressed sensing, network analysis.

C. Ruiz, Professor, Computer Science Department. Ph.D., University of Maryland, 1996. Data mining, machine learning, artificial intelligence, genomics, clinical medicine.

D. M. Strong, Professor and Department Head, Robert A. Foisie School of Business. Ph.D., Carnegie Mellon University, 1988. Healthcare and business data analytics, computing applications in organizations.

A. C. Trapp, Associate Professor, Robert A. Foisie Business School. Ph.D., University of Pittsburgh, 2011. Mathematical optimization and analytics with applications to benefit society, focusing on improving outcomes of vulnerable populations.

R. Zekavat, Professor, Physics Department, Ph.D., Colorado state University, 2002. Statistical Signal Processing, Sensor Data Analysis and Machine Learning.

J. Zou, Associate Professor, Mathematical Sciences Department. Ph.D., University of Connecticut, 2009. Financial time series and spatial statistics with applications to epidemiology, public health and climate change.

Affiliated Faculty

E. O. Agu, Professor, Computer Science Department. Ph.D., University of Massachusetts, 2001. Mobile and ubiquitous health, machine and deep learning applications, and computer graphics.

I. Arroyo, Associate Professor, Social Science and Policy Studies. D.Ed., University of Massachusetts, 2003. Learning with novel technologies, multimedia learning, intelligent tutoring systems, personalized learning systems.

J. Beck, Associate Professor, Computer Science Department. Ph.D., University of Massachusetts, 2001. Educational data mining.

M. Y. Blais, Associate Teaching Professor and Associate Department Head, Mathematical Sciences. Ph.D., Cornell University, 2006. Liquidity modeling, operations research, volatility derivatives, leverage.

D. Brown, III, Associate Professor, Department of Electrical and Computer Engineering. Ph.D., Cornell University, 2000. Communication systems and networking, signal processing, information theory.

L. Capogna, Department Head, Professor, Mathematical Sciences. Ph.D., University of Purdue, 1996. Partial differential equations, calculus of variations and analytic aspects of quasiconformal mappings, sub-Riemannian geometry, minimal surfaces and mean curvature flow.

S. Djamasbi, Professor, Robert A. Foisie School of Business. Ph.D., University of Hawaii, 2004. Management information systems.

J. Doyle, Associate Professor, Social Science and Policy Studies. Ph.D., University of Colorado-Boulder, 1991. Mental models of complex systems, environmental cognition and behavior.

M. Elmes, Professor, Robert A. Foisie School of Business. Ph.D., Syracuse University, 1998. Interpersonal and group dynamics in complex organizations, leading change, leadership ethics.

B. Faber, Professor, Humanities & Arts Department. Ph.D., English University of Utah, 1998. Organizations and change, health care operations and data-intensive methods for understanding health systems and medical practices.

L. Fichera, Assistant Professor; Ph.D., University of Genoa/Italian Institute of Technology.Continuum robotics, medical robotics, surgical robotics, image-guided surgery, laser-based surgery, medical devices.

Return to Table of Contents

T. Guo, Assistant Professor, Computer Science; Ph.D., University of Massachusetts Amherst, 2016. Distributed systems, cloud computing, data-intensive systems.

A. Hall-Phillips, Associate Professor, Robert A. Foisie School of Business. Ph.D., Purdue University, 2011. Consumer behavior, business-to-business marketing, small business.

N. T. Heffernan, Professor, Computer Science Department and Co-Director Learning Sciences and Technologies. Ph.D., Carnegie Mellon University, 2001. Educational data mining, Machine Learning applied to educational context. A/B testing.

X. Huang, Professor, Department of Electrical and Computer Engineering. Ph.D., Virginia Tech, 2001. Reconfigurable computing, ubiquitous computing and RFID.

M. Humi, Professor, Mathematical Sciences. Ph.D., Weizmann Institute of Science, Rehovot, Israel, 1969. Development and application of mathematical methods to atmospheric research and satellites orbits.

S. Johnson, Professor, Robert A. Foisie School of Business. Ph.D., Cornell University, 1989. Healthcare delivery processes, EHR systems, process analysis and demand.

R. Konrad, Associate Professor, Robert A. Foisie School of Business. Ph.D., Purdue University, 2009. Decision-analytic modeling, discrete event stochastic simulation-based optimization.

D. Korkin, Professor in Computer Science, and BCB Program Director; Ph.D., University of New Brunswick, Canada, 2003. Big data analytics in life sciences, machine learning and its applications, visualization of complex biological data, network science, bioinformatics and personalized medicine.

F. Miller, Associate Professor, Robert A. Foisie School of Business. Ph.D., Michigan State University, The Eli Broad School of Management, 2007. Accounting, psychology and economics interact.

R. Neamtu, Associate Teaching Professor, Computer Science; Ph.D., Worcester Polytechnic Institute.

S. D. Olson, Associate Professor, Mathematical Sciences. Ph.D., North Carolina State University, 2008. Mathematical biology, chemical signaling, mechanics, and hydrodynamics.

M. Radzicki, Associate Professor, Social Science and Policy Studies. Ph.D., University of Notre Dame, 1985. System dynamics modeling, agent-based modeling, predictive analytics.

E. Ryder, Associate Professor, Biology and Biotechnology. Ph.D., Harvard University, 1993. Developmental neurobiology, genetics, bioinformatics, computational biology.

A. Sales, Assistant Professor, Mathematical Sciences. Ph.D., University of Michigan, 2013. Methods for causal inference using administrative or high-dimensional data, especially in education.

M. Sarkis, Professor, Mathematical Sciences. Ph.D., New York University, 1994. Numerical analysis, finite element methods

G. Sarkozy, Professor, Computer Science Department. Ph.D., Rutgers University, 1994. Graph theory, discrete mathematics, and theoretical computer science.

S. Sturm, Associate Professor, Mathematical Sciences. Ph.D., Technical University of Berlin, Germany, 2010. Financial mathematics and engineering.

B. Sunar, Professor, Department of Electrical and Computer Engineering. Ph.D., Oregon State University, 1998. Cryptography, network security, high performance computing

D. Tang, Professor, Mathematical Sciences. Ph.D., University of Wisconsin-Madison, 1988. Computational biomathematics, biology and bioengineering.

S. Taylor, Professor and Dean, ad Interim, Robert A. Foisie School of Business. Ph.D., Boston College, 2000. Organizational aesthetics, reflective practice, first person research, authentic leadership.

B. Tulu, Associate Professor, Robert A. Foisie School of Business. Ph.D., Claremont Graduate University, 2006. Design and development health information technologies.

B. Vernescu, Professor, Mathematical Sciences. Ph.D., Institute of Mathematics, Bucharest, Romania, 1989. Partial differential equations, homogenization, calculus of variation.

H. Walker, Professor, Mathematical Sciences. Ph.D., New York University, 1970. Computational mathematics, numerical methods for systems of linear and nonlinear equations.

S. L. Weekes, Professor, Mathematical Sciences. Ph.D., University of Michigan, 1995. Numerical methods, mathematical modeling, dynamic materials.

J. R. Whitehill, Assistant Professor, Computer Science Department. Ph.D., University of California, San Diego, 2012. Machine learning, crowdsourcing, automated teaching, human behavior recognition.

E. V. Wilson, Associate Teaching Professor, Robert A. Foisie School of Business. Ph.D., University of Colorado-Boulder, 1995. E-health, computer mediated communications.

Z. Wu, Associate Professor, Mathematical Sciences. Ph.D., Yale University, 2009. Big data statistical analytics, bioinformatics.

Z. Zhang, Associate Professor; Ph.D., Brown University, 2014, Shanghai University, 2011.Numerical analysis, scientific computing, computational and applied mathematics, uncertainty qualification.

J. Zhu, Professor, Robert A. Foisie School of Business. Ph.D., University of Massachusetts, 1998. Performance evaluation and benchmarking, sustainable design and performance.

Faculty Research

Our faculty work in many areas related to Data Science, including in:

- Big data and high performance analytics
- Bioinformatics and genomic data bases
- Business intelligence and predictive analytics
- Cybersecurity analytics
- Cryptography and data security
- Educational data mining
- Financial decision making
- Healthcare data analytics
- Internet big data analysis
- Large-scale data management and infrastructures
- Machine learning, data mining & knowledge discovery

Return to Table of Contents

- Signal processing and information theory
- Social media analytics
- Statistical learning
- Visual and numerical analysis of large data sets

Program of Study

The WPI Data Science (DS) program offers graduate studies toward an M.S., B.S./M.S. and Ph.D. Degree as well as a Certificate in Data Science. This Data Science program educates professionals, Data Scientists, with interdisciplinary skills in analytics, computing, statistics, and business intelligence. Key skills include the ability to recognize problems that can be solved with data analytics, apply the appropriate technologies on a given data problem, and communicate those solutions effectively to relevant stakeholders. Our faculty, together with our industrial partners, provide students with the resources and opportunities to engage in practical, purpose-driven projects, formal course work, and mentored interdisciplinary research work. This Data Science program requires advanced, in-depth course work in business, innovation, data analytics, computing, and statistical foundations. The program is designed to provide focused study in an area of interest to the student, ranging from general data analytics, computing, mathematical analytics, and business analytics, to specialized concentrations in financial analytics, healthcare analytics, biomedical analytics, analytics for sustainability, and learning sciences, among others. Due to their increased interdisciplinary perspective, our graduates will have a clear competitive advantage over professionals who are trained in a single discipline, such as business administration, statistics, or computer science, and who are seeking to work in the data analytic industry. As such, they will be poised to successfully become leaders in Data Science, helping to formalize and realize its vision.

The graduate degree program in Data Science is designed to produce the future generation of data scientists who are proficient in their ability to:

- Assess the suitability of, apply, and advance state-of-art data analytics tools and methods from data analysis, statistics, data mining, data management, computational thinking, big data algorithms, and visualization to bring about transformative solutions to important real-world problems across a number of domains.
- Bring to bear their integrative, interdisciplinary knowledge and skills in the core disciplines central to Data Science (Computing, Statistics, and Business) to understand and then to explain analytics results and their applicability and validity to those responsible for solving real-world problems.
- Serve as visionary leaders and project managers in data analytics, with the technical, and professional knowledge and skills needed for the current and future career demands of data scientists working on impactful projects.

Admissions Requirements

Students applying to the graduate degree program in Data Science (DS) are expected to have a bachelor's degree with a strong quantitative and computational background including coursework in programming, data structures, algorithms, univariate and multivariate calculus, linear algebra and introductory statistics. Students with a bachelor's degrees in computer science, mathematics, business, engineering and quantitative sciences would typically qualify if they meet the above background requirements. A strong applicant who is missing background coursework may be admitted with the expectation that he or she will take and pass one or more undergraduate courses in this area of deficiency either during the summer prior to admission or within the first semester after admission. The determination of what course or courses will satisfy this provision will be made by the DS Program Review Board. Students applying to the Certificate in Data Science are expected to meet the same qualifications described above.

Degree Requirements for the M.S. Degree

Students pursuing the M.S. degree in Data Science must complete a minimum of 33 credits of relevant work at the graduate level. These 33 credits must include the core coursework requirements in Data Science (see below) and either a 3-credit Graduate Qualifying Project (GQP) or a 9-credit M.S. thesis. These M.S. degree requirements have been designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively and also students who are pursuing a combined B.S./M.S. degree.

Upon acceptance to the M.S. program, students will be assigned an academic advisor who will work with the student to correctly prepare a Plan of Study. This Plan of Study must then be approved by the Data Science Program Review Board.

The Data Science M.S. Degree (GQP Project-based)

Graduate Qualifying Project
(3 credits)

Concentration and Electives
(15 credits)

Mathematical Analytics (3 credits)

Data Access & Management (3 credits)

Data Analytics & Mining (3 credits)

Business Intelligence & Case Studies (3 credits)

Introduction to Data Science
(3 credits)

The Data Science M.S. Degree (M.S. Thesis based)

M.S. Thesis
(9 credits)

Concentration and Electives
(9 credits)

Mathematical Analytics (3 credits)

Data Access & Management (3 credits)

Data Analytics & Mining (3 credits)

Business Intelligence & Case Studies (3 credits)

Introduction to Data Science
(3 credits)

Core Data Science Coursework Requirement (15 credits)

Students in the M.S. program must take both courses in the Integrative Data Science category and one (1) course from each of the other core Data Science categories listed below:

Integrative Data Science (required):

DS 501. Introduction to Data Science

Return to Table of Contents

Mathematical Analytics (Select one):

*MA 543/DS 502. Statistical Methods for Data Science

MA 542. Regression Analysis

MA 554. Applied Multivariate Analysis

Data Access and Management (Select one):

*CS 542. Database Management Systems

*MIS 571. Database Applications Development

CS 561. Advanced Topics in Database Systems

CS 585/DS 503. Big Data Management

Data Analytics and Mining (Select one):

*CS 548. Knowledge Discovery and Data Mining

CS 539. Machine Learning

CS 541/DS 541. Deep Learning

CS 586/DS 504. Big Data Analytics

Business Intelligence and Case Studies (Select one):

*MIS 584. Business Intelligence

MKT 568. Data Mining Business Applications

If a student does not have prior background in a particular core category, then it is advised that the student take the course with an asterisk * in the title within that category. If two or more courses have an asterisk *, then the student may select either of these courses based on their personal interest and background. Students *must* take at least 1 course in each of these core areas, but are encouraged to take several. Additional courses taken in a core category will count as electives and/or concentration courses as described below.

Graduate Qualifying Project GQP or M.S. Thesis

A student in the M.S. program must complete one of the following two options:

- **3-credit Graduate Qualifying Project.** (DS 598) This project is most commonly done in teams, and will provide a capstone experience in applying data science skills to a real-world problem. It will be carried out in cooperation with a sponsor or an industrial partner, and must be approved and overseen by a faculty member affiliated with the Data Science Program. The graduate qualifying project is typically taken for 3 graduate credits. With permission by the instructor, a student can take the course a second time for additional credit, up to a total of 6 graduate credits. This means that the student could take two offerings of the course concurrently in one semester or could register for three credits in one semester and another three credits in a subsequent semester. A student that follows this practice-oriented project option must gain sufficient Data Science depth by selecting at least 2 courses beyond the required Data Science core courses from among the electives below within the same area of concentration.
- **9-credit Master's Thesis.** (DS 599) A thesis in the Data Science Program consists of a research or development project worth a *minimum* of 9 graduate credit hours. Students interested in research, and in particular those who are considering a Ph.D. in a related area, are encouraged to select the M.S. thesis option. Any affiliated DS faculty may serve as the thesis advisor. If the advisor is not a tenure-track faculty at WPI, then a DS affiliated tenure-track faculty member must serve as the thesis co-advisor. A thesis proposal must be approved by both the DS Program Review Board *and* the student's advisor before the student can register for more than three thesis credits. The student must then satisfactorily complete a written thesis and present the results to the DS faculty in a public presentation.

Electives and Areas of Concentration

(9-15 credits)

A student seeking an M.S. in Data Science program must take course work from the Program electives listed below in order to satisfy the remainder of the 33 credit requirement. An elective may be any of these graduate-level courses, with the restriction that *no more than 16 credits of the 33-credit Data Science degree program may be courses offered by the School of Business.*

While the core areas ensure that students have adequate coverage of essential Data Science knowledge and skills, the wide variety of electives enable students to tailor their Data Science degree program to domain and technique areas of personal interest. Students are expected to select elective course work to produce a consistent program of study. While the core coursework requirements provide the needed breadth in Data Science core categories, students will gain depth in one or several concentrations by choosing appropriate electives from the list of pre-approved courses relevant to data science.

Other courses beyond the pre-approved Program electives may be chosen as electives, but only with *prior approval* by the DS Program Review Board, and if consistent with the student's Plan of Study. For example, students might choose to concentrate their data science expertise on areas of physics, engineering, or sciences, not captured in the electives below. Independent study and directed research courses also require *prior approval* by the DS Program Review Board.

List of Program Elective Courses:

Relevant Business Graduate Courses (a maximum of 16 graduate credits of School of Business coursework may count toward the M.S. in Data Science):

ACC 500. Accounting and Finance Fundamentals

ACC 502. Financial Intelligence and Strategic Decision Making

ACC 505. Performance Measurement and Management

BUS 500. Business Law, Ethics and Social Responsibility

FIN 500. Financial Information and Management

FIN 503. Financial Decision Making for Value Creation

FIN 504. Financial Statement Analysis and Valuation

MIS 500. Innovating with Information Systems

MIS 571. Database Applications Development

MIS 573. Systems Design and Development

MIS 576. Project Management

MIS 581. Information Technology Policy and Strategy

MIS 583. User Experience Applications

MIS 584. Business Intelligence

MIS 585. User Experience Design

MIS 587. Business Applications in Machine Learning

MKT 568. Data Mining Business Applications

OBC 505. Teaming and Organizing for Innovation

OBC 506. The Heart of Leadership: Power, Reflection and Interpersonal Skills

OIE 501. Designing Operations for Competitive Advantage

OIE 542. Risk Management and Decision Analysis

OIE 544. Supply Chain Analysis and Design

OIE 552. Modeling and Optimizing Processes

OIE 559. Optimization Methods for Business Analytics

Relevant Computer Science Graduate Courses:

CS 5007. Introduction to Applications of Computer Science with Data Structures and Algorithms

CS 5084. Introduction to Algorithms: Design and Analysis

CS 504. Analysis of Computations and Systems

CS 509. Design of Software Systems

CS 525. Topics in Computer Science (with prior approval of the Program Review Committee to determine relevancy)

CS 528. Mobile and Ubiquitous Computing

CS 534. Artificial Intelligence

CS 536. Programming Language Design

CS 539. Machine Learning

CS 541/DS 541. Deep Learning

CS 542. Database Management Systems

CS 545. Digital Image Processing

CS 546. Human-Computer Interaction

CS 547/DS 547. Information Retrieval

CS 548. Knowledge Discovery and Data Mining

CS 549. Computer Vision

CS 561. Advanced Topics in Database Systems

CS 573. Data Visualization

CS 584. Algorithms: Design and Analysis

CS 585/DS 503. Big Data Management

CS 586/DS 504. Big Data Analytics

Note: Students may not receive credit for both CS 5084 and CS 584

Relevant Mathematical Sciences Graduate Courses:

MA 511. Applied Statistics for Engineers and Scientists

MA 517/DS 517. Mathematical Foundations for Data Science

MA 529. Stochastic Processes

MA 540. Probability and Mathematical Statistics I

MA 541. Probability and Mathematical Statistics II

MA 542. Regression Analysis

MA 543/DS 502. Statistical Methods for Data Science

MA 546. Design and Analysis of Experiments

MA 547. Design and Analysis of Observational and Sampling Studies

MA 549. Analysis of Lifetime Data

MA 550. Time Series Analysis

MA 552. Distribution-Free and Robust Statistical Methods

MA 554. Applied Multivariate Analysis

MA 556. Applied Bayesian Statistics

Relevant Learning Sciences and Technology Program Graduate Courses:

CS 565. User Modeling

CS 566. Graphical Models For Reasoning Under Uncertainty

CS 567. Empirical Methods For Human-Centered Computing

PSY 505. Advanced Methods and Analysis for the Learning and Social Sciences

Relevant Bioinformatics and Computational Biology Program Courses:

BCB 501. Bioinformatics

BCB 502/CS 582. Biovisualization

BCB 503/CS 583. Biological and Biomedical Database Mining

BCB 504/MA 584. Statistical Methods in Genetics and Bioinformatics

Relevant Biomedical Engineering Courses:

BME 595. Special Topics: Machine Learning for Biomedical Informatics

Relevant Electrical and Computer Engineering Department Courses:

ECE 502. Analysis of Probabilistic Signals And Systems

ECE 503. Digital Signal Processing

ECE 504. Analysis of Deterministic Signals And Systems

ECE 578/ CS 578. Cryptography and Data Security

ECE 630. Advanced Topics in Signal Processing

ECE 673/CS 673. Advanced Cryptography

ECE 5311. Information Theory and Coding

Other Relevant Graduate Courses and Concentration Areas:

Beyond courses in the three core disciplines of computer science, business, and statistics, relevant graduate courses in other potential areas of concentration, such as Finance, Manufacturing, Healthcare, National Security, Engineering, Fraud Detection, Science, Smart Grid Management, Sustainability and the like, may be added in the future to the above list of pre-approved Program electives.

Specializations of the Data Science Degree:

Specializations of the Data Science degree in targeted areas of high societal impact ranging from Health Care to National Security may be designed in the future. We expect these specializations to naturally fit into the flexible structure of the Data Science degree framework.

For the B.S./M.S.

The requirements for the proposed M.S. in Data Science are structured so that undergraduate student would be able to pursue a five-year Bachelor's/Master's program, in which the Bachelor's degree is awarded in any major offered at WPI and the Master's degree is awarded in Data Science. Students enrolled in the B.S./M.S. program must satisfy all the program requirements of their respective B.S. degree *and* all the program requirements of the M.S. degree in Data Science. WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelor's/Master's program. This overlap can be achieved through the following mechanisms. Students may double-count courses towards both their undergraduate and graduate degrees whose credit hours total no more than *40 percent of the 33 credit hours required for the M.S. degree in Data Science*, and that meet all other requirements for each degree. These courses can include graduate courses as well as certain undergraduate 4000-level course as long as the undergraduate course is acceptable in place of a corresponding graduate course that satisfies a Data Science M.S. requirement.

In consultation with the academic advisor, the student prepares a Plan of Study outlining the selections chosen to satisfy the B.S./M.S. degree requirements, including the courses that will be double-counted. This Plan of Study must then be approved by the Data Science Program.

As a university wide rule, the B.S./M.S. double counting credits can be applied for only while the student is an undergraduate student.

Double Counting Credits From 4000-Level Courses

For the following 4000-Level courses, two graduate credits will be earned towards the B.S./M.S. degree if the student achieves grade B or higher, or otherwise with the instructor's approval. In addition, faculty may offer, at their discretion, an additional 1/6 undergraduate unit, or equivalently a 1 graduate credit, for completing additional work in the course. To obtain this additional credit, the student must register for 1/6 undergraduate unit of independent study at the 4000-level or a 1 graduate credit independent study at the 500-level, with permission from the instructor.

Courses from Computer Science
CS 4120 Analysis of Algorithms
CS 4341 Introduction to Artificial Intelligence
CS 4432 Database Systems II
CS 4445 Data Mining and Knowledge Discovery
CS 4531 Machine Learning
CS 4802 BioVisualization
CS 4803 Biological and Biomedical Database Mining
Courses from Mathematical Sciences
MA 4235 Mathematical Optimization
MA 4603 Statistical Methods in Genetics and Bioinformatics
MA 4631 Probability and Mathematical Statistics I
MA 4632 Probability and Mathematical Statistics II
DS 4635/MA 4635 Data Analytics and Statistical Learning

Other 4000-level courses not listed above, including 4000-level independent study courses, require a petition and approval from the Data Science Graduate Committee before they can double-count for the B.S./M.S. degree.

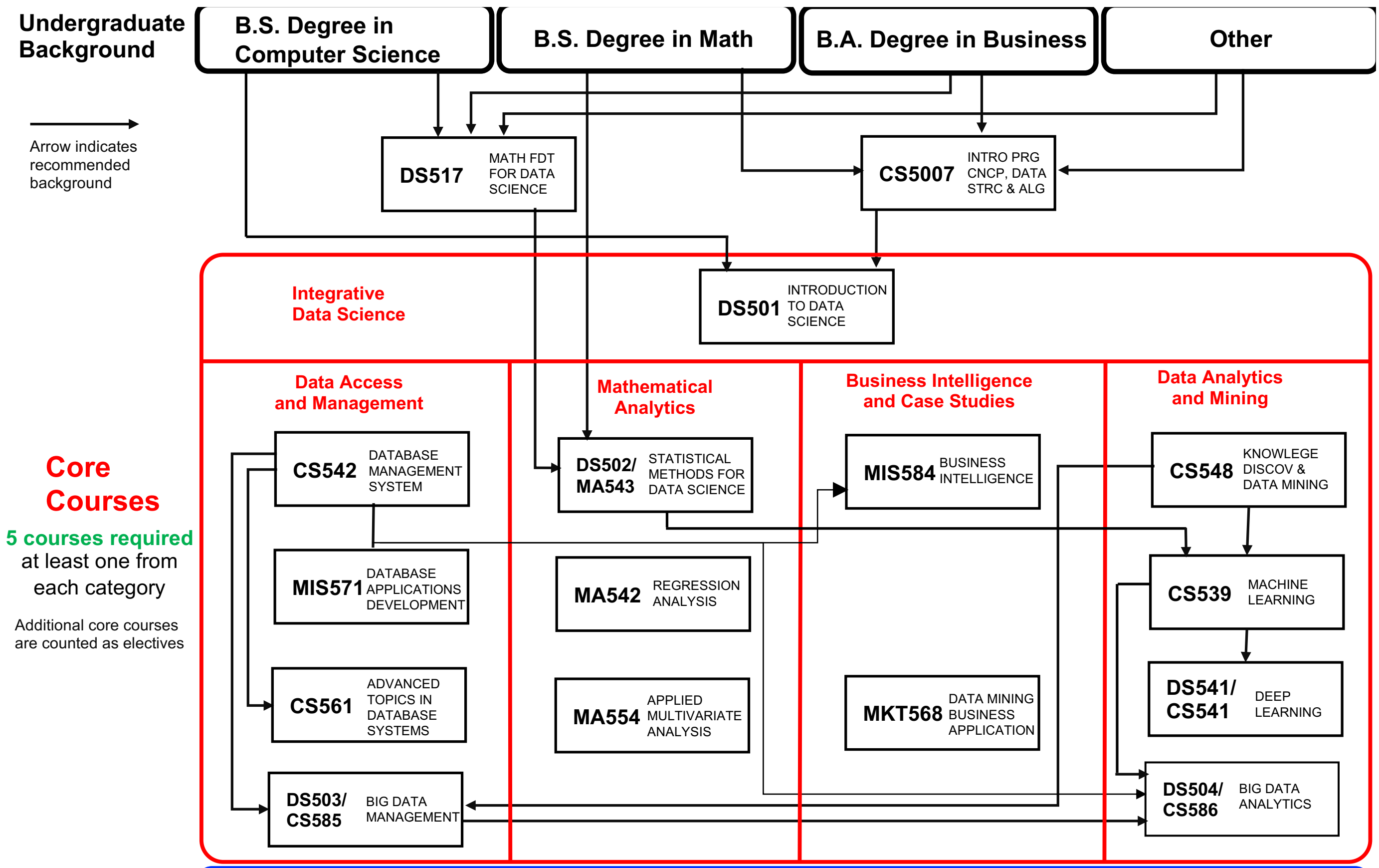
Restricted Undergraduate and Graduate Course Pairs

Some undergraduate and graduate courses have significant overlap in their content. The following table lists these courses. A student can receive credit towards their M.S. degree for at most one of the two courses in any row of this table.

Courses from Computer Science	
Undergraduate Course	**Graduate Course**
CS 4341 Introduction to Artificial Intelligence	CS 534 Artificial Intelligence
CS 4432 Database Systems II	CS 542 Database Management Systems
CS 4445 Data Mining and Knowledge Discovery	CS 548 Knowledge Discovery and Data Mining
CS 4803 Biological and Biomedical Database Mining	CS 583 Biological and Biomedical Database Mining
Courses from Mathematical Sciences	
Undergraduate Course	**Graduate Course**
MA 4631 Probability and Mathematical Statistics I	MA 540 Probability and Mathematical Statistics I
MA 4632 Probability and Mathematical Statistics II	MA 541 Probability and Mathematical Statistics II
DS 4635/MA 4635 Data Analytics and Statistical Learning	MA 543/DS 502 Statistical Methods for Data Science

Return to Table of Contents

Data Science Graduate Course Chart



Electives

3 or 5 courses

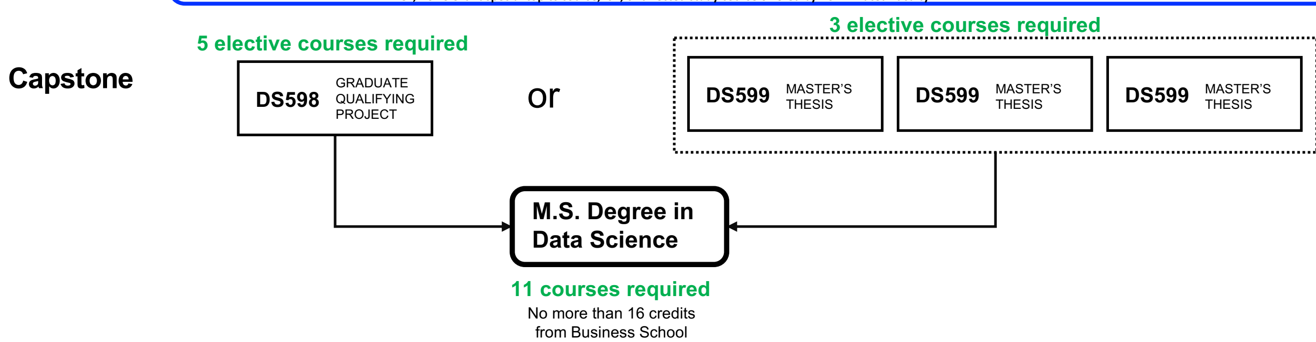
CS 5007. Introduction to Prog. Concepts, Data Structures and Algorithms
CS 5084. Introduction to Algos: Design and Analysis
CS 504. Analysis of Computations and Systems
CS 509. Design of Software Systems
CS 528. Mobile and Ubiquitous Computing
CS 534. Artificial Intelligence
CS 536. Programming Language Design
CS 539. Machine Learning
CS 541/DS541. Deep Learning
CS 542. Database Management Systems
CS 545. Digital Image Processing
CS 546. Human-Computer Interaction
CS 547/DS 547. Information Retrieval
CS 548. Knowledge Discovery and Data Mining
CS 549. Computer Vision
CS 561. Advanced Topics in Database Systems
CS 565. User Modeling
CS 566. Graphical Models For Reasoning Under Uncertainty
CS 567. Emp. Methods For Human-Cent. Computing
CS 573. Data Visualization
CS 584. Algorithms: Design and Analysis
CS 585/DS 503. Big Data Management
CS 586/DS 504. Big Data Analytics

MA 511. Applied Statistics For Eng. & Scientists
MA 529. Stochastic Processes
MA 540. Probability and Mathematical Statistics I
MA 541. Probability and Mathematical Statistics II
MA 542. Regression Analysis
MA 543/DS 502. Statistical Methods for Data Science
MA 546. Design and Analysis of Experiments
MA 547. Design and Analysis of Observational and Sampling Studies
MA 549. Analysis of Lifetime Data
MA 550. Time Series Analysis
MA 552. Distribution-Free and Robust Statistical Methods
MA 554. Applied Multivariate Analysis
MA 556. Applied Bayesian Statistics

ACC 500 Accounting and Finance Fundamentals.
ACC 502 Financial Intelligence and Strategic Decision-Making
ACC 505 Perform. Measurement and Mang.
BUS 500 Buss. Law, Ethics and Social Resp.
FIN 500 Financial Information and Management
FIN 503 Financial Decision Making for V. Creation
FIN 504 Financial Statement A. and Valuation
MIS 500 Innovating with Information Systems
MIS 571 Database Applications Development
MIS 573 Systems Design and Development
MIS 576 Project Management
MIS 581 Information Tech. Policy and Strategy
MIS 583 User Experience Applications
MIS 584 Business Intelligence
MIS 585 User Experience Design
MIS 587. Business Applications in Machine Learning
MKT 568 Data Mining Business Applications
OBC 505 Teaming and Organizing for Innovation
OBC 506 The Heart of Leadership: Power…
OIE 501 Designing Op. for Competitive Advantage
OIE 542 Risk Management and Decision Analysis
OIE 544 Supply Chain Analysis and Design
OIE 552 Modeling and Optimizing Processes
OIE 559 Opt. Methods for Business Analytics

PSY 505. Advanced Methods and Analysis for the Learning and Social Sciences
BCB 501. Bioinformatics
BCB 502/CS 582. BioVisualization
BCB 503/CS 583. Biological and Biomedical Database Mining
BCB 504/MA 584. Statistical Methods in Genetics and Bioinformatics
BME 595. Special Topics: Machine Learning for Biomedical Informatics
ECE 502. Analysis of Probabilistic Signals And Systems
ECE 503. Digital Signal Processing
ECE 504. Analysis of Deterministic Signals And Systems
ECE 578/ CS 578. Cryptography and Data Security
ECE 630. Advanced Topics in Signal Processing
ECE 673. Advanced Cryptography
ECE 5311. Information Theory and Coding

Or, DS-relevant special topics course, ISP, or directed study course offered by DS Affiliated Faculty



Last Updated: 10/07/2019

Return to Table of Contents

Satisfying Data Science Core Areas

B.S./M.S. students can use the B.S./M.S. credits to satisfy a core area requirement if any of the following conditions is met: (1) The undergraduate course under consideration must appear in one of the tables above, and the corresponding graduate course must satisfy the core area requirement. (2) The undergraduate course or independent study/project work is not in the tables listed above but it is deemed to satisfy the core area. This requires submitting a petition along with a detailed course description and syllabus to the Data Science Program for final decision.

For the Graduate Certificate

The certificate program in Data Science prepares students to harness, analyze and interpret data in real-world applications. The certificate consists of 12 credits that must satisfy the following criteria: (1) DS 501 is mandatory, (2) two additional courses must be from the Data Science core courses listed in the graduate catalog, and (3) the remaining credits can be earned from any Data Science elective course(s) listed in the graduate catalog or otherwise approved by the program.

The certificate courses may be subsequently applied to a degree program at WPI, including the M.S. degree in Data Science, providing the courses meet the requirements of that degree program.

Students who have completed or are currently enrolled in a graduate degree at WPI (other than Data Science) can double count graduate credits from their graduate degree to meet up to one-third of the graduate credits for a (subsequent) Graduate Certificate in Data Science.

For the Ph.D.

Students are advised to contact the program for detailed rules, as there are program guidelines, in addition to the university's requirements, for the Ph.D. degree.

Upon admission, the student is assigned an academic advisor and together they design a Plan of Study during the first semester of the student's Ph.D. program. A Ph.D. student without a prior M.S. degree is required to take the M.S. thesis Option to engage in research early on.

The student must satisfy the Ph.D. Qualification Requirement, which include the core breadth and core depth competency requirements. The Core breadth competency includes at least one course in each of the core Data Science areas, while the later implies that the student must take at least two courses in two of these core areas. Only courses in which the student has obtained an A or a B grade can be used to satisfy these two competency requirements; with 4 of these 7 courses having to be an A letter grade.

In addition the Ph.D. Qualification requirement also includes the Qualifying Examination. These qualification requirements are described in the Graduate Regulations on the Data Science program website https://www.wpi.edu/academics/departments/data-science.

Upon successful completion of the Ph.D. qualifying requirement, the student becomes a Data Science Ph.D. candidate. The student's Dissertation Committee must be formed within the first year of candidacy. With approval from the Data Science Steering Committee, the student selects a research advisor. Also with approval from the Data Science Steering Committee, the student and research advisor select three additional members, at least one of whom must be from a core data science department different than that of the research advisor and at least one must be from outside of WPI. The Dissertation Committee will be responsible for approving the dissertation proposal and the final dissertation manuscript.

The Ph.D. degree requirements consist of a coursework component and a research component, which together must total at least 60 credit hours beyond the master's degree requirement for Ph.D. students who earned their MS degree in a program other than Data Science at WPI. The coursework and research component must total at least 57 credit hours for students who earn both a master's degree and Ph.D. degree in Data Science at WPI. The coursework component consists of at least 30 coursework credits, as specified on the Data Science program website https://www.wpi.edu/academics/departments/data-science.

The student may also enroll for research credits, but is only allowed up to 18 research credits prior to the acceptance of the written dissertation proposal by her Dissertation Committee. With approval of the Dissertation Committee, the student applies for and takes the dissertation proposal examination, usually within one year of the Ph.D. candidacy.

The Ph.D. research component consists of at least 30 credits (including any research credits earned prior to the acceptance of the dissertation proposal and excluding any research credits applied toward a master's degree) leading to a dissertation and a public defense, which must be approved by the student's Dissertation Committee.

Affiliated Departments and Programs

This is a joint program administered by the Computer Science Department, Mathematical Sciences Department, and the Robert A. Foisie School of Business. Closely affiliated departments also include Social Science and Policy Studies Department, Learning Sciences and Technologies Program, Bioinformatics and Computational Biology Program, and the Electrical and Computer Engineering Department. Data Science faculty are comprised of faculty interested in Data Science graduate education and research and who hold advanced degrees.

Industrial Relationships

In collaboration with WPI's Corporate and Professional Education, the Data Science faculty work with industrial, government and academic partners who serve on an Advisory Board to help shape the WPI Data Science program and its offerings to assure its continued relevancy. In addition, these Advisory Board members provide input on industrial hiring needs, offer projects and internships to Data Science students, and serve as employers of our graduates.

Return to Table of Contents

Course Descriptions

All courses are 3 graduate credits unless otherwise stated.

DS 501. Introduction to Data Science

Introduction to Data Science provides an overview of Data Science, covering a broad selection of key challenges in and methodologies for working with big data. Topics to be covered include data collection, integration, management, modeling, analysis, visualization, prediction and informed decision making, as well as data security and data privacy. This introductory course is integrative across the core disciplines of Data Science, including databases, data warehousing, statistics, data mining, data visualization, high performance computing, cloud computing, and business intelligence. Professional skills, such as communication, presentation, and storytelling with data, will be fostered. Students will acquire a working knowledge of data science through hands-on projects and case studies in a variety of business, engineering, social sciences, or life sciences domains. Issues of ethics, leadership, and teamwork are highlighted. Prerequisites: None beyond meeting the Data Science admission criteria.

DS 502/MA 543. Statistical Methods for Data Science

Statistical Methods for Data Science surveys the statistical methods most useful in data science applications. Topics covered include predictive modeling methods, including multiple linear regression, and time series, data dimension reduction, discrimination and classification methods, clustering methods, and committee methods. Students will implement these methods using statistical software. Prerequisites: DS 517/MA 517, Statistics at the level of MA 2611 and MA 2612 and linear algebra at the level of MA 2071.

DS 503/CS 585. Big Data Management

Big Data Management deals with emerging applications in science and engineering disciplines that generate and collect data at unprecedented speed, scale, and complexity that need to be managed and analyzed efficiently. This course introduces the latest techniques and infrastructures developed for big data management including parallel and distributed database systems, map-reduce infrastructures, scalable platforms for complex data types, stream processing systems, and cloud-based computing. Query processing, optimization, access methods, storage layouts, and energy management techniques developed on these infrastructures will be covered. Students are expected to engage in hands-on projects using one or more of these technologies. Prerequisites: A beginning course in databases at the level of CS 4432 or equivalent knowledge, and programming experience.

DS 504/CS 586. Big Data Analytics

Big Data Analytics addresses the obstacle that innovation and discoveries are no longer hindered by the ability to collect data, but by the ability to summarize, analyze, and discover knowledge from the collected data in a scalable fashion. This course covers computational techniques and algorithms for analyzing and mining patterns in large-scale datasets. Techniques studied address data analysis issues related to data volume (scalable and distributed analysis), data velocity (high-speed data streams), data variety (complex, heterogeneous, or unstructured data), and data veracity (data uncertainty). Techniques include mining and machine learning techniques for complex data types, and scale-up and scale-out strategies that leverage big data infrastructures. Real-world applications using these techniques, for instance social media analysis and scientific data mining, are selectively discussed. Students are expected to engage in hands-on projects using one or more of these technologies. Prerequisites: A beginning course in databases and a beginning course in data mining, or equivalent knowledge, and programming experience.

DS/MA 517. Mathematical Foundations for Data Science

The foci of this class are the essential statistics and linear algebra skills required for Data Science students. The class builds the foundation for theoretical and computational abilities of the students to analyze high dimensional data sets. Topics covered include Bayes' theorem, the central limit theorem, hypothesis testing, linear equations, linear transformations, matrix algebra, eigenvalues and eigenvectors, and sampling techniques, including Bootstrap and Markov chain Monte Carlo. Students will use these techniques while engaging in hands-on projects with real data. Prerequisites: Some knowledge of integral and differential calculus is recommended.

DS/CS 541. Deep Learning

This course will offer a mathematical and practical perspective on artificial neural networks for machine learning. Students will learn about the most prominent network architectures including multilayer feedforward neural networks, convolutional neural networks (CNNs), auto-encoders, recurrent neural networks (RNNs), and generative-adversarial networks (GANs). This course will also teach students optimization and regularization techniques used to train them -- such as backpropagation, stochastic gradient descent, dropout, pooling, and batch normalization. Connections to related machine learning techniques and algorithms, such as probabilistic graphical models, will be explored. In addition to understanding the mathematics behind deep learning, students will also engage in hands-on course projects. Students will have the opportunity to train neural networks for a wide range of applications, such as object detection, facial expression recognition, handwriting analysis, and natural language processing. Prerequisite: Machine Learning (CS 539), and knowledge of Linear Algebra (such as MA 2071) and Algorithms (such as CS 2223).

DS/CS 547. Information Retrieval

This course introduces the theory, design, and implementation of text-based and Web-based information retrieval systems. Students learn the key concepts and models relevant to information retrieval and natural language processing on large-scale corpus such as the Web and social systems. Topics include vector space model, crawling, indexing, web search, ranking, recommender systems, embedding and language model. Prerequisites: statistical learning at the level of DS 502/MA 543 and programming skills at the level of CS 5007.

DS/ECE 577. Machine Learning in Cybersecurity.

Machine Learning has proven immensely effective in a diverse set of applications. This trend has reached a new high with the application of Deep Learning virtually in any application domain. This course studies the applications of Machine Learning in the sub domain of Cybersecurity by introducing a plethora of case studies including anomaly detection in networks and computing, side-channel analysis, user authentication and biometrics etc. These case studies are discussed in detail in class, and further examples of potential applications of Machine Learning techniques including Deep Learning are outlined. The course has a strong hands-on component, i.e. students are given datasets of specific security applications and are required to perform simulations.

DS 5900. Data Science Internship

(0 to 3 credits)

The internship is an elective-credit option designed to provide an opportunity to put into practice the principles studied in previous Data Science courses. Internships will be tailored to the specific interests of the student. Each internship must be carried out in cooperation with a sponsoring organization, generally from off campus and must be approved and advised by a core faculty member in the Data Science program. The internship must include proposal, design and documentation phases. Following the internship, the student will report on his or her internship activities in a mode outlined by the supervising faculty member. Students are limited to counting a maximum of 3 internship credits towards their degree requirements for the M.S. degree in Data Science. We expect a full-time graduate student to take on only part-time (20 hours or less of) internship work during the regular academic semester, while a full-time internship of 40 hours per week is appropriate during the summer semester as long as the student does not take a full class load at the same time. Internship credit cannot be used towards a certificate degree in Data Science. The internship may not be completed at the student's current place of employment. Prerequisites: Registration for internship credit requires prior approval and signature by the academic advisor.

DS 595. Special Topics in Data Science

Special Topics in Data Science is course offering that will cover a topic of current interest in detail. This serves as a flexible vehicle to provide a one-time offering of topics of current interest as well as to offer new topics before they are made into a permanent course. Prerequisites: will vary with topic.

DS 596. Independent Study

Independent Study, as the name suggests, is a course that allows a student to study a chosen topic in Data Science under the guidance of a faculty member affiliated with the Data Science program. The student must produce a written report to satisfy the course requirement.

DS 597. Directed Research

Directed Research study, conducted under the guidance of a faculty member affiliated with the Data Science Program, investigates the challenges and techniques central to data science, and aims to develop novel approaches and techniques towards solving these challenges. The student who chooses this course must produce a written report to fulfil the course requirement.

DS 598. Graduate Qualifying Project

This 3-credit graduate qualifying project, done in teams, can be taken a second time for credit with permission by the instructor, up to a total of 6 credits. The project is to be carried out in cooperation with a sponsor or industrial partner. It must be overseen by a faculty member affiliated with the Data Science Program. This offering integrates theory and practice of Data Science, and includes the utilization of tools and techniques acquired in the Data Science Program. In addition to a written report, this project must be presented in a formal presentation to faculty of the Data Science program and sponsors. Professional development skills, such as communication, teamwork, leadership, and collaboration, along with storytelling, will be practiced.
Prerequisites: DS students should have completed at least 24 credits of the DS MS degree, or consent of the instructor, before starting the GQP project class. DS students seeking to take this course a second time for credits, up to a total of 6 credits, must get the instructor's approval. Non-DS students must get the instructor's approval before taking this course for any number of credits.

DS 599. Master's Thesis in Data Science

The Master's Thesis in Data Science consists of a research and development project worth a minimum of 9 graduate credit hours and is advised by a faculty member affiliated with the Data Science Program. A thesis proposal must be approved by the DS Program Review Board and the student's advisor, before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document, and present the results to the DS faculty in a public presentation.

DS 699. Dissertation Research.

Intended for doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations. (Prerequisite: Consent of Dissertation Advisor.)

Return to Table of Contents

Electrical and Computer Engineering

Faculty and Research Interests

D. R. Brown, Professor and Interim Department Head; Ph.D., Cornell University. Wireless communications and networks, cooperative communication systems, synchronization, efficient resource allocation, distributed decision making, game-theoretic analysis of networks, peer-to-peer networks, cognitive radio, software defined radio, computationally efficient signal processing, security in wireless communication systems.

M. Amissah, Assistant Teaching Professor; Ph.D., Old Dominion University. Research focus: Model Based Systems Engineering, Systems Architecture, Complexity Science.

S. V. Bhada, Assistant Professor, Ph.D., University of Alabama at Huntsville. Modeling and Analysis of Policy Content and Systems Engineering.

E. A. Clancy, Professor; Ph.D., MIT. Biomedical signal processing and modeling, biomedical instrumentation.

A. Clark, Assistant Professor; Ph.D., University of Washington. Security, control of cyber-physical systems.

R. J. Duckworth, Associate Professor; Ph.D., Nottingham University. Embedded computer system design, computer architecture, real-time systems, wireless instrumentation, rapid prototyping, logic synthesis, location and tracking systems.

J. Fu, Assistant Professor; Ph.D., University of Delaware. Reactive robotic systems, multi-robot coordination, optimal control of hybrid systems and design of adaptive semi-autonomous systems.

F. Ganji, Assistant Professor; Ph.D. Technical University of Berlin (Germany). Security, machine learning, hardware security, post-quantum cryptography.

U. Guler, Assistant Professor, Ph.D., Bogozici University, Turkey. Smart Health Applications, Implantables and Wearables, Sensor Interfaces, Neural Interfaces, RF-Energy Harvesting, Wireless Power and Data Transfer, Power Management IC, Biomedical Security, and, Low Power Analog/Mixed Signal IC Design.

X. Huang, Professor; Ph.D., Virginia Tech. Autonomous vehicles; computer vision; machine learning; FPGA and VLSI design; internet of things.

R. Ludwig, Professor and Associate Department Head; Ph .D., Colorado State University. Design of RF coils for magnetic resonance imaging; amplifier design; nondestructive material evaluation.

Y. Mahmoud, Assistant Professor; Ph.D., University of Waterloo, Canada. Solar energy conversion, renewable energy integration, power electronics, dispatchability in renewable energy systems, control and operation of micro grids, and smart cities.

S. N. Makarov, Professor; Ph.D., Dr.Sci, St. Petersburg State University (Russian Federation). Bioelectromagnetics, Electromagnetic therapeutic devices, Antennas and electromagnetic sensors. Human body CAD models.

J. A. McNeill, Professor and Interim Dean of Engineering; Ph.D., Boston University. Analog IC design; high-speed imaging; mixed-signal circuit characterization.

W. R. Michalson, Professor; Ph.D., Worcester Polytechnic Institute. Navigation and tracking; high-performance embedded computer systems.

K. Pahlavan, Professor; Ph.D., Worcester Polytechnic Institute. Wireless networks.

P. Schaumont, Professor; Ph.D., University of California at Los Angeles. Hardware security; reverse engineering; embedded systems; hardware-software codesign; digital IC design.

B. Sunar, Professor; Ph .D., Oregon State University . Cybersecurity; applied cryptography; high-speed computing.

E. Uzunovic, Assistant Teaching Professor; Ph.D., University of Waterloo, Canada. High voltage, direct current power transmission, advanced power distribution, power electronics including smart inverters.

A. M. Wyglinski, Professor; Ph.D., McGill University. Wireless communication systems engineering, vehicular technology, cognitive radio, software-defined radio, autonomous vehicles, wireless spectrum, vehicular security, cyber-physical systems.

Emeritus

D. Cyganski, Professor

A. E. Emanuel, Professor

F. J. Looft, Professor

J. A. Orr, Professor

P.C. Pedersen, Professor

Programs of Study

The Electrical and Computer Engineering (ECE) Department offers programs leading to M.Eng., M.S. and Ph.D. degrees in electrical and computer engineering, an M.Eng. degree in power systems engineering (PSE), as well as graduate and advanced certificates. The following general areas of specialization are available to help students structure their graduate courses: Smart Connected Systems, Integrated System Design, Cybersecurity, Power Systems.

The M.S. ECE degree is designed to provide an individual with advanced knowledge in one or more electrical and computer engineering areas via successful completion of at least 21 credits of WPI ECE graduate courses (including M.S. thesis credit), combined with up to 9 credits of coursework from computer science, mathematics, physics and other engineering disciplines.

The M.Eng. ECE and M.Eng. PSE degrees are tailored for individuals seeking an industrial career path. Similar to the M.S. degree, the M.Eng. degree requires the successful completion of at least 21 credits of WPI ECE graduate courses (specific course requirements for the M.S. ECE and M.S. PSE degrees are discussed below). In contrast to the M.S. degree, the M.Eng. degree allows up to 9 credits on non-ECE courses to be chosen as management courses and does not include a thesis option.

Return to Table of Contents

Admission Requirements

Master's Program

Students with a B.S. degree in electrical engineering or electrical and computer engineering may submit an application for admission to the Master's program. There are three degree options in the Master's program: An M.S. in Electrical and Computer Engineering, an M.Eng. in Electrical and Computer Engineering, and an M.Eng. in Power Systems Engineering. Admission to the Master's program will be based on a review of the application and associated references.

Applicants without a B.S. degree in electrical engineering or electrical and computer engineering, but who hold a B.S. degree in mathematics, computer engineering, physics or another engineering discipline, may also apply for admission to the Master's program in the Electrical and Computer Engineering Department. If admitted, the applicant will be provided with required courses necessary to reach a background equivalent to the B.S. degree in electrical engineering or electrical and computer engineering, which will depend on the applicant's specific background.

Applicants with the bachelor of technology or the bachelor of engineering technology degree must typically complete about 1-1/2 years of undergraduate study in electrical engineering before they can be admitted to the graduate program. If admitted, the applicant will be provided with required courses necessary to reach a background equivalent to the B.S. degree in electrical engineering or electrical and computer engineering, which will depend on the applicant's specific background.

Ph.D. Program

Students with a Master's degree in electrical and computer engineering may apply for the doctoral program of study. Admission to the Ph.D. program will be based on a review of the application and associated references. Students with a Bachelor of Science degree in electrical and computer engineering may also apply to the Ph.D. program. Students with a strong background in areas other than Electrical and Computer Engineering will also be considered for admission into the Ph.D. program. If admitted (based on review of the application and associated references), the applicant may be approved for direct admission to the Ph.D. program, or to an M.S.-Ph.D.. program sequence. Applicants possessing and M.S. degree in electrical and computer engineering from WPI that have not been directly admitted to the Ph.D. program are still required to submit an application and associated references for consideration, with the exception of GRE scores, TOEFL scores, and the application fee.

Certificate Requirements

The ECE Department offers advanced certificate and graduate certificate programs. Please visit https://www.wpi.edu/academics/study/electrical-computer-engineering-certificates

Degree Requirements

There are three degree options within the Master's program in the Electrical and Computer Engineering Department: A Master of Engineering in Electrical and Computer Engineering (M.Eng. ECE), a Master of Science in Electrical and Computer Engineering (M.S. ECE), and a Master of Engineering in Power Systems Engineering (M.Eng. PSE).

Master of Science ECE

Students pursuing the M.S. ECE degree may take either the non-thesis option, which requires 30 graduate credits in course work, independent study, or directed research, or the thesis option, with a total of 30 graduate credits including a 9-credit thesis. In either case, at least 21 of the 30 credits must be graduate level activity (designated 500-, 5000-, or 600-level) in the field of electrical and computer engineering (course prefix ECE) offered by WPI. The remaining credits may be either at the 4000 (maximum of six credits) or the 500 level in computer science (CS), physics (PH), engineering (BME, CHE, CE, ECE, FP, MFE, MTE, ME, RBE, and SYS) and/or mathematics (MA). The complete program must be approved by the student's advisor and the Graduate Program Committee.

Master of Engineering ECE

Students pursuing the M.Eng. ECE degree require 30 graduate credits in course work, independent study, or directed research. There is no thesis option for the M.Eng. ECE degree program. At least 21 of the 30 credits must be graduate level activity (designated 500-, 5000-, or 600-level) in the field of electrical and computer engineering (course prefix ECE) offered by WPI. The remaining credits may be either at the 4000 level (maximum of six credits) or at the graduate level in computer science (CS), physics (PH), engineering (BME, CHE, CE, ECE FP, MFE, MTE, ME, RBE, and SYS), mathematics (MA), and/or from the School of Business (ACC, BUS, ETR, FIN, MIS, MKT, OBC, and OIE). The complete program must be approved by the student's advisor and the Graduate Program Committee.

Master of Engineering PSE

The M.Eng. PSE is primarily delivered to industry professionals at a variety of off-campus locations; students should contact the ECE office staff regarding course availability. Students pursuing the M.Eng. PSE degree require 30 graduate credits in course work, independent study, or directed research. There is no thesis option for the M.Eng. PSE degree program. At least 21 of the 30 credits must be graduate level activity in the field of electrical and computer engineering offered by WPI; of these 21 credits, at least 15 must be in the field of power system engineering (course prefix ECE with course numbers from 5500 through 5599). The remaining courses may be either at the 4000 level (maximum of six credits) or at the graduate level (designated as 500-, 5000-, or 600-level) in computer science (CS), physics (PH), engineering (BME, CHE, CE, ECE, FP, MFE, MTE, ME, RBE, and SYS), mathematics (MA), and/or from the School of Business (ACC, BUS, ETR, FIN, MIS, MKT, OBC, and OIE).

Program of Study

Each student must submit a program of study for approval by the student's advisor, the ECE Department Graduate Program Committee and the ECE Department Head. To ensure that the Program of Study is acceptable, students should, in consultation with their advisor, submit it to the ECE Department Graduate Secretary prior to the end of the semester following admission into the graduate program. Students must obtain prior approval from the ECE Department Graduate Program Committee for the substitution of courses in other disciplines as part of their academic program.

All full-time students in the Master's degree program (with the exception of B.S./M.S. students as noted below) are required to attend and pass the two graduate seminar courses, ECE 596A (fall semester) and ECE 596B (spring semester). See course listings for details.

Thesis Option

Students pursuing an M.S. ECE degree that are financially supported by the department in the form of teaching assistantship, research assistantship, or fellowship are required to complete a thesis. The thesis option is not available for students pursuing an M.Eng. ECE or M.Eng. PSE degree. M.S. thesis research involves 9 credit hours of work, registered under the designation ECE 599, normally spread over at least one academic year. For students completing the M.S. thesis as part of their degree requirements, a thesis committee will be set up during the first semester of thesis work. This committee will be selected by the student in consultation with the major advisor and will consist of the thesis advisor (who must be a full-time WPI ECE faculty member) and at least two other faculty members whose expertise will aid the student's research program. An oral presentation before the Thesis Committee and a general audience is required. In addition, all WPI thesis regulations must be followed.

Non-Thesis Option

Although the thesis is optional for M.S. ECE students not financially supported by the department, and there is no thesis option available for M.Eng. ECE or M.Eng. PSE students, all M.Eng. and M.S. students are encouraged to include a research component in their graduate program. A directed research project, registered under the designation ECE 598, involves a minimum of 3 credit hours of work under the supervision of a faculty member. The task is limited to a well-defined goal. Note that the Graduate Program committee will not allow credit received under the thesis designation (ECE 599) to be applied toward an M.Eng. ECE degree, M.Eng. PSE degree, or non-thesis M.S. ECE degree.

Transfer Credit

Students may petition to transfer a maximum of 15 graduate semester credits, with a grade of B or better, after they have enrolled in the degree program. This may be made up of a combination of up to 9 credits from the WPI ECE graduate courses taken prior to formal admission and up to 9 credits from other academic institutions. Transfer credit will not be allowed for undergraduate level courses taken at other institutions. In general, transfer credit will not be allowed for any WPI undergraduate courses used to fulfill undergraduate degree requirements; however note that there are exceptions in the case of students enrolled in the B.S./M.S. program.

For the Ph.D.

The degree of doctor of philosophy is conferred on candidates in recognition of high scientific attainments and the ability to carry on original research. The following is a list of requirements for students intending to obtain a Ph.D. in Electrical and Computer Engineering.

Coursework and Residency Requirements

Students must complete 60 or more credits of graduate work beyond the credit required for the Master of Science degree in Electrical and Computer Engineering. Of the 60 credits, at least 30 credits must be research registered under the designation ECE 699. The doctoral student must also establish two minors in fields outside of electrical engineering. Physics, mathematics and/or computer science are usually recommended. Each student selects the minors in consultation with their Research Advisor. At least 6 credits of graduate work is required in each minor area. Courses with an ECE designation which are cross-listed in the course offerings of another department cannot be used toward fulfilling the requirements of a minor area.

All doctoral students are required to attend and pass two offerings of the ECE graduate seminar courses, ECE 596A (fall semester) and ECE 596B (spring semester). These students may either enroll in the same ECE graduate seminar course offered in two different semesters, or enroll in each of the two different ECE graduate seminar courses. Note that enrollment in these two courses is required regardless if the student has already successfully passed these courses and counted them towards the requirements of an M.S. degree or equivalent credit.

Full-time residency at WPI for at least one academic year is required while working toward a Ph.D. degree.

Research Advisor and Committee Selection

The doctoral student is required to select a Research Advisor and their Committee prior to scheduling their Diagnostic Examination. This will usually occur prior to the start of the student's second semester in the graduate program. The Research Advisor and all members of the Committee must hold doctoral degrees. The Research Advisor must be a full-time ECE faculty member. The Committee must consist of at least two faculty members, at least one of which must be an ECE faculty member and at least one of which must be from outside the ECE department or from outside WPI. The Committee is usually selected by the student in consultation with the Research Advisor. All members of the committee must be approved by the Research Advisor.

A completed Research Advisor and Committee Selection form must be filed with the ECE department prior to taking the Diagnostic Exam. A student may change their Research Advisor or members of their Committee by submitting a new Research Advisor and Committee Selection form to the Graduate Secretary. Changes to the student's Research Advisor after completion of the diagnostic examination must be approved by the ECE Graduate Program Committee. Changes to the student's Committee after completion of the area examination must be approved by the ECE Graduate Program Committee.

Diagnostic Examination Requirement

The doctoral student is required to complete the diagnostic examination requirement during the first year beyond the M.S. degree (or equivalent number of credits, for students admitted directly to the Ph.D. program) with a grade of Pass. The diagnostic examination is scheduled with the student's Research Advisor and Committee. Prior to scheduling the diagnostic examination, a student must have a completed Research Advisor and Committee Selection form on file in the ECE department.

The diagnostic examination is administered by the student's Research Advisor and at least one member of the Committee. Full participation of the Committee is recommended. At the discretion of the research advisor, additional faculty outside of the student's committee may also participate in the diagnostic examination. The diagnostic examination is intended to be an opportunity to evaluate the student's level of academic preparation and identify any shortcomings in the student's background upon entrance to the Ph.D. program. The format and duration of the diagnostic examination is at the discretion of the student's Research Advisor and Committee. The examination may be written or oral and may include questions to test the general background of the student as well as questions specific to the student's intended area of research.

The Research Advisor and Committee determine the outcome of the diagnostic examination (Pass, Repeat, or Fail) and any required remediation intended to address shortcomings identified in the student's background. A grade of Fail will result in dismissal from the graduate program. A grade of Repeat requires the student to reschedule and retake the diagnostic examination. A grade of Pass is expected to also include a summary of any prescribed remediation including, but not limited to, coursework, reading assignments, and/or independent study. Irrespective of outcome of the examination, a diagnostic examination completion form, signed by the student's Research Advisor and committee, must be filed with the ECE department upon completion of the examination.

Upon successful completion of the Diagnostic Examination, each doctoral student must submit a program of study to the ECE Department Graduate Secretary for approval by the student's research advisor, the ECE Department Graduate Program Committee and the ECE Department Head. The program of study should be completed in consultation with the student's research advisor and should include specific course work designed to address any shortcomings identified in the student's background during the Diagnostic Examination.

Area Examination Requirement

The doctoral student is required to pass the area examination before writing a dissertation. The area examination is intended to be an opportunity for the student's Advisor and Committee members to evaluate the suitability, scope, and novelty of the student's proposed dissertation topic. The format of the area examination is at the discretion of the student's Advisor and Committee but will typically include a presentation by the student describing the current state of their research field, their planned research activities, and the expected contributions of their work.

Students are eligible to take the area examination after they have successfully completed the diagnostic examination and have completed at least three semesters of coursework in the graduate program. All Ph.D. students are required to successfully complete the area examination prior to the completion of their seventh semester in the graduate program. Failure to successfully complete the area examination prior to the end of the student's seventh semester will be considered a failure to make satisfactory academic progress.

The Research Advisor and Committee determine the Pass/Fail outcome of the area examination. A grade of Fail will result in dismissal from the graduate program. Area examination completion forms must be signed by the student's Research Advisor and Committee Members and filed with the ECE department upon completion of the examination.

Dissertation Requirement

All Ph.D. students must complete and orally defend a dissertation prepared under the general supervision of their Research Advisor. The research described in the dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Research Advisor and Committee certify the quality and originality of the dissertation research, the satisfactory execution of the dissertation and the preparedness of the defense.

The Graduate Secretary must be notified of a student's defense at least seven days prior to the date of the defense, without exception. A student may not schedule a defense until at least three months after they have completed the area examination.

For the Combined B.S./M.S. Program

A WPI student accepted into the B.S./M.S. program may use 12 credit hours of work for both the B.S. and M.S. degrees. Note that students will not be able to receive an M.Eng. ECE or M.Eng. PSE degree via this particular program. At least 6 credit hours must be from graduate courses (including graduate level independent study and special topics courses), and none may be lower than the 4000-level. No extra work is required in the 4000-level courses. A grade of B or better is required for any course to be counted toward both degrees. A student must define the 12 credit hours at the time of applying to the B.S./M.S. program. Applications will not be considered if they are submitted prior to the second half of the applicant's junior year. Ideally, applications (including recommendations) should be completed by the early part of the last term of the junior year.

At the start of Term A in the senior year, but no later than at the time of application, students are required to submit to the graduate coordinator of the Electrical and Computer Engineering Department a list of proposed courses to be taken as part of the M.S. degree program. A copy of the student's academic transcript (grade report) must be included with the application.

All students in the B.S./M.S. program in Electrical and Computer Engineering who have completed their B.S. degree must register for at least six credits per semester until they complete 30 credits toward their M.S. degree. If fewer than six credits are required to complete the M.S. degree, then the student must register for at least the number of credits required to complete the degree. If a student double counts a full 12 credits for both the M.S. and B.S. degrees, then the remaining 18 credits must be completed within 3 semesters of graduate work (1.5 years). Students who double count less than 12 credits for both the M.S. and B.S. degree will be allowed an additional semester (2 years) to complete the degree.

All B.S./M.S. students are required to attend and pass one of the graduate seminar courses, either ECE 596A (fall semester) or ECE 596B (spring semester).

Students enrolled in the B.S./M.S. program in Electrical and Computer Engineering may petition for permission to use a single graduate course (3 credits maximum) taken at other institutions to satisfy ECE B.S./M.S. degree requirements. The course must be at the graduate level and the student must have earned a grade of B or better to be considered for transfer credit.

Certificates in Power Systems

These specialized programs raise professional competency levels of protection power systems engineers and focus on topics like the protection and control aspects of the power industry.

These certificates consist of 12-18 credits of graduate coursework. https://www.wpi.edu/academics/online/study/power-systems-online-certificates

Electrical and Computer Engineering Research Laboratories/Centers

Analog/Mixed Signal Microelectronics Laboratory

Prof. McNeill

The Analog and Mixed Signal Microelectronics Laboratory focuses on the continuation of research in self-calibrating analog to-digital converter architectures and low-jitter clock generation; funded by NSF, Allegro Microsystems, and Analog Devices. www.wpi.edu/+ECE

Bioelectromagnetics & Antenna Laboratory

Prof. Makarov/Prof. Noetscher

The Laboratory develops modeling and hardware design of various electronic systems and devices for biomedical (diagnostic and therapeutic) and wireless applications.

Center for Advanced Integrated Radio Navigation (CAIRN)

Prof. Michalson

The Center for Advanced, Integrated, Radio Navigation (CAIRN) mission is the development of radio systems that integrate communications and navigation functions. Basic research into radio design (analog and digital), wireless ad hoc networking and positioning is performed for both indoor and outdoor radio environments. The laboratory develops, designs, implements, and field-tests a variety of radio and navigation systems. Housed within the laboratory is the Public Safety Integration Center, which focuses on the development and deployment of communications, information, and navigation technologies for public safety applications. Representative projects: Radio systems for indoor positioning, Digital radios for public safety systems, Simulation of wireless ad hoc networks for public safety applications. http://www.wpi.edu/academics/ece/cairn/index.html

Center for Wireless Information Networking Studies (CWINS)

Prof. Pahlavan

The mission of the Center for Wireless Information Network Studies is the analysis of wideband radio propagation for design and performance evaluation of wireless access and localization techniques. The current focus of research is on body area networking and in particular localization of wireless video capsule endoscope inside the small intestine. The past focus of the center were on indoor geolocation and Wi-Fi localization for application in smart devices and robots. The center was established in 1985 as the world's first research center for the design of wireless local area networks. More details on the center are available at www.cwins.wpi.edu.

Collective Intelligence and Bionic Robotics (CIBR) Lab

Prof. Fu (ECE) and Prof. Li (ME)

CIBR lab is a joint lab between ECE faculty Jie Fu and ME faculty Zhi Li, under the Robotics Engineering Program. Our research focus is to bring a joint force between control theory, machine learning and robotics to achieve two major objectives: First, by leveraging learning-based control design, we aim to develop algorithms to achieve provably safe, adaptive and robust performance in autonomous systems in the presence of uncertain and dynamical environment. Second, we aim to build the algorithmic foundation for bionic robotics that facilitates a seamless collaboration between human and robots, with applications to advanced manufacturing, health, and medical robotics.

Embedded Computer Laboratory

Prof. Huang

The mission of the Embedded Computing Lab is to solve important problems of embedded computer systems, including theories, architectures, circuits, and systems. Our current research is focused on ASIC, FPGA and SoC design for signal processing, wireless communications, error correction coding, reconfigurable computing, and computing acceleration. Our research goal is to create new architectures and circuit designs to facilitate high-speed information processing at minimum power consumption. http://computing.wpi.edu/

Laboratory for Sensory and Physiologic Signal Processing – L(SP)²

Prof. Clancy

The mission of the Laboratory for Sensory and Physiologic Signal Processing L(SP)2 is to employ signal processing, mathematical modeling, and other electrical and computer engineering skills to study applications involving electromyography (EMG — the electrical activity of skeletal muscle). Researchers are improving the detection and interpretation of EMG for such uses as the control of powered prosthetic limbs, restoration of gait after stroke or traumatic brain injury, musculoskeletal modeling, and clinical/scientific assessment of neurologic function. http://users.wpi.edu/~ted/

Renewable Energy Innovations Laboratory

Prof. Mahmoud

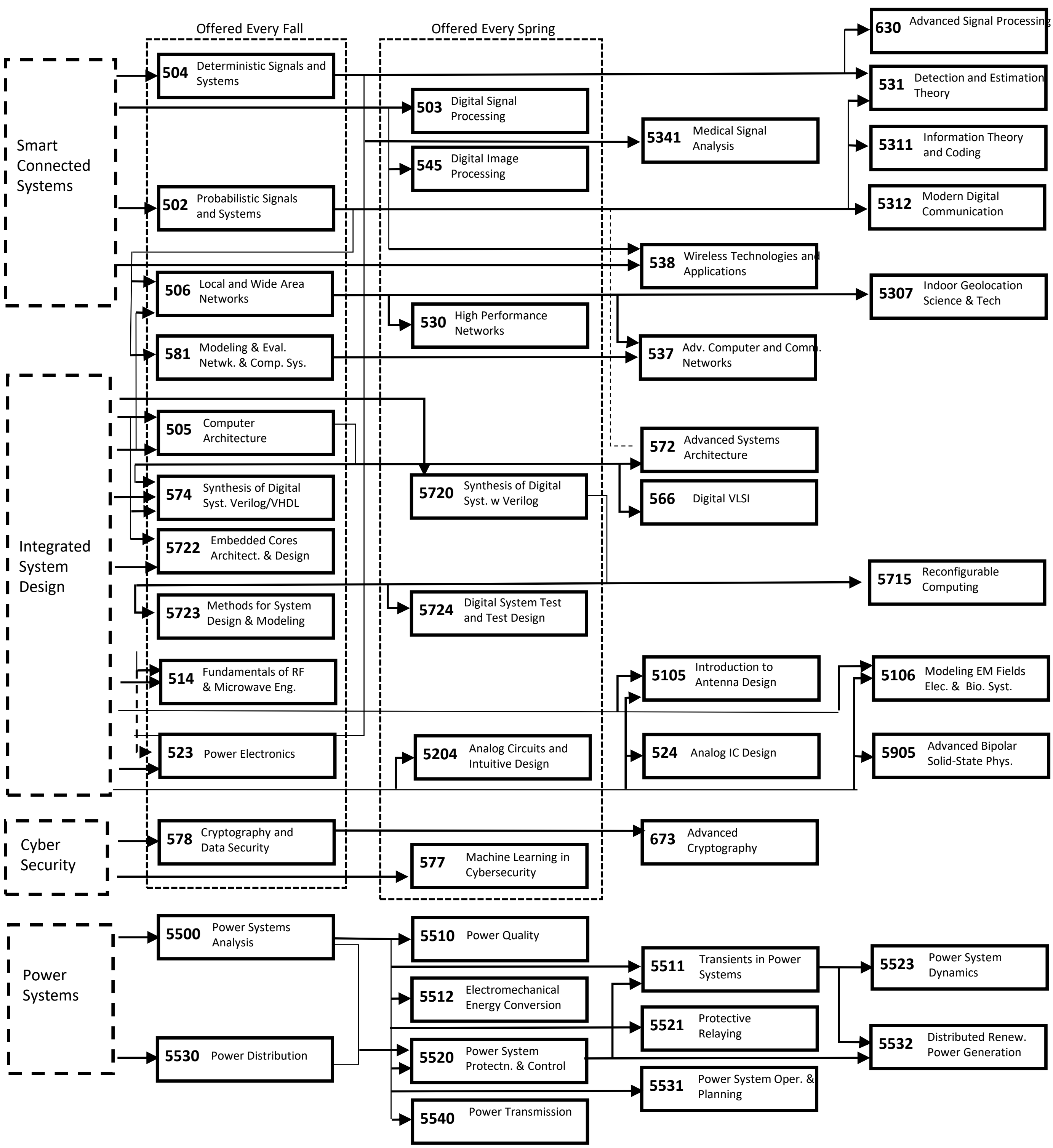
Our lab emphasizes all aspects of innovations in renewable energy systems for the conversion, delivery, and its use in electrical form. Our aim is to contribute in expanding the utilization of renewable energy resources in the world by addressing technical challenges impeding their utilization, including reducing their cost, and improving their overall efficiency, operation, control, integration and reliability. Our objective is also to commercialize and transfer our developed technologies to market. https://www.wpi.edu/people/member/yamahmoud

Center for Imaging and Sensing (CIS)

Prof. Ludwig

The lab has access to high-field and ultra high-field magnetic resonance imaging (MRI) systems for use in functional and anatomical imaging. Major research focuses on visualization of elastic vibrations in the female breast. A novel

ECE Graduate Course Chart 2020-21



Return to Table of Contents

coil geometry was designed that proved more efficient at generating these strong gradients when compared with conventional coil technology. Research has resulted in the design of special-purpose radio frequency array coil systems for breast cancer diagnosis, bone density determination, and stroke. The lab has successfully tested its single-tuned and dual-tuned prototypes at various sites throughout the U.S. in clinical MRI systems.
www.wpi.edu/+ECE

ICAS Lab

Prof. U. Guler

The research program of ICAS Lab. explores the designs of a range of biomedical devices from implantable devices to wearable devices that ensure device security, personal privacy, accurate bio-sensing, and reliable operation and proposes possible directions of study that tackle the fundamental challenges including; sustainable energy harvesting systems for continuous long-term health monitoring (how sustainable energy harvesting and its efficient storage and usage are possible for continuous long-term personal health monitoring), secure bio-implants and wearables (how the security of all these sensors associated with smart healthcare will be assured in terms of maintaining proper functionality of devices and protecting private information), and wireless sensor Interfaces for medical and general purpose IoTs (how accurate and reliable sensing interfaces will be able to receive very low-amplitude signals coming from various environments, such as inside the body).
https://icaslab.org/

Secure Cyber-Physical Systems Lab

Prof. Clark

Cyber-Physical Systems (CPS) are comprised of tightly integrated cyber (sensing, communication, computation) and physical (actuation) components in applications including transportation, medicine, energy, and housing. The goal of our lab is to develop foundations for CPS with provable guarantees on safety, performance, and security, in the presence of dynamic environments, random faults and failures, and malicious attacks.

Signal Processing and Information Networking Laboratory (SPINLab)

Prof. Brown

SPINLab was established in 2002 to investigate fundamental and applied problems in signal processing, communication systems, and networking. Our current focus is on the development of network carrier synchronization schemes to facilitate distributed beamforming and space-time coded cooperative transmission. We are also working on techniques for optimal resource allocation in multiuser communication systems and the application of game-theoretic tools to analyze selfish behavior in cooperative communication systems. SPINLab offers research opportunities at both the graduate and undergraduate levels. For more details, please see the SPINLab Web page at http://spinlab.wpi.edu.

Vernam Laboratory

Profs. Schaumont, Sunar, Eisenbarth, Doroz, Martin (Mathematics), Mus

The mission of the Vernam Group is to address both short-term and long-term security problems spanning several disciplines. Group members are focused on developing new security technologies to ensure the safety of all facets of the communication and computation infrastructure bridging the gap between cutting edge research and solid engineering practices, thus, providing the perfect setting for the education of next generation security experts. http://v.wpi.edu/

Wireless Innovation Laboratory (WILab)

Prof. Wyglinski

The Wireless Innovation Laboratory (WILab) conducts fundamental and applied research in wireless communication systems engineering and vehicular technology. Consisting of approximately 750 sq ft of prime research space as well as state-of-the-art software tool and experimentation equipment, this facility focuses on devising new solutions and new knowledge in the areas of cognitive radio, connected vehicles, software-defined radio, autonomous vehicles, wireless spectrum and resource allocation, vehicular security, prototype wireless systems, vehicular networking, cyber-physical systems, and advanced signal processing algorithms. WILab has been extensively funded via numerous sponsors from both government and industry, including the National Science Foundation, MathWorks, Office of Naval Research, Toyota InfoTechnology Center USA, and the MITRE Corporation. For more details, please see the WILab website at http://www.Wireless.WPI.edu.

Course Descriptions

All courses are 3 credits unless otherwise noted.

ECE 502. Analysis of Probabilistic Signals and Systems

Applications of probability theory and its engineering applications. Random variables, distribution and density functions. Functions of random variables, moments and characteristic functions. Sequences of random variables, stochastic convergence and the central limit theorem. Concept of a stochastic process, stationary processes and ergodicity. Correlation functions, spectral analysis and their application to linear systems. Mean square estimation. (Prerequisite: Undergraduate course in signals and systems.)

ECE 503. Digital Signal Processing

Discrete-time signals and systems, frequency analysis, sampling of continuous time signals, the z-transform, implementation of discrete time systems, the discrete Fourier transform, fast Fourier transform algorithms, filter design techniques. (Prerequisites: Courses in complex variables, basic signals and systems.)

ECE 504. Analysis of Deterministic Signals and Systems

Review of Fourier series and linear algebra. Fourier transforms, Laplace transforms, Z transforms and their interrelationship. State space modeling of continuous-time and discrete-time systems. Canonical forms, solution of state equations, controllability, observability and stability of linear systems. Pole placement via state feedback, observer design, Lyapunov stability analysis. (Prerequisite: Undergraduate course in signals and systems.)

ECE 505. Computer Architecture

This course introduces the fundamentals of computer system architecture and organization. Topics include CPU structure and function, addressing modes, instruction formats, memory system organization, memory mapping and hierarchies, concepts of cache and virtual memories, storage systems, standard local buses, high-performance I/O, computer communication, basic principles of operating systems, multi-programming, multiprocessing, pipelining and memory management. The architecture principles underlying RISC and CISC processors are presented in detail. The course also includes a number of design projects, including simulating a target machine, architecture using a high-level language (HLL). (Prerequisites: Undergraduate course in logic circuits and microprocessor system design, as well as proficiency in assembly language and a structured high-level language such as C or Pascal.)

ECE 506. Introduction to Local and Wide Area Networks

This course provides an introduction to the theory and practice of the design of computer communications networks according to IEEE 802 standard model for lower layers and IETF standard for TCP/IP higher layers. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types including local area and wide area networks are introduced, as are evolving network technologies. The theory, design and performance of local area networks are emphasized. The course includes application of queueing analysis to performance analysis of medium access control (MAC) and application of communication theory in design of physical layer (PHY). (Prerequisites: familiarity to MATLAB programming is assumed. Background in undergraduate level courses in networking, probability, statistic, and signal processing.)

ECE 5105. Introduction to Antenna Design

This course is intended for graduate and senior-level undergraduate students. The course provides an introduction to major antennas and antenna types for wireless communications. Basic antenna characteristics are studied. Both narrowband and broadband antennas as well as antenna arrays are considered. One emphasis is made on learning antenna modeling software, ANSYS HFSS and Antenna Toolbox of MATLAB. Another emphasis is made on the basic measurement hardware. The course structure is directed toward understanding antenna operations and basic antenna design, and enables students with a broad background to take this course. Course topics in particular include: transmitter-receiver antenna circuit models, antenna radiation and radiation parameters, dipole antenna family, patch antenna family, loop antenna family, reflector antennas, small antennas, antenna matching and tuning, antenna arrays, on-body and in-body antennas, antenna measurements and modeling. (Prerequisites: undergraduate analog electronics, college MATLAB, and basic introductory knowledge of electromagnetic theory - ECE 2019 and ECE 3113).

ECE 5106. Modeling of Electromagnetic Fields in Electrical & Biological Systems

This course is intended for graduate and senior-level undergraduate students. Modern numerical methods and major software packages are reviewed in application to modeling electrical and biomedical sensors, bioelectromagnetics, wireless communications (including wireless body area networks), and power electronics. The course begins with an introduction to computational mesh generation. Triangular surface meshes, volumetric tetrahedral meshes, voxel meshes, and computational human phantoms are studied. The boundary element method or the method-of-moments is introduced and detailed, followed by a review of the finite element method for electromagnetic problems. The finite-difference time-domain method is another major topic of the course. The course also covers ray tracing algorithms in application to wireless networks. (Prerequisites: college MATLAB, differential and integral calculus).

ECE 514. Fundamentals of RF and MW Engineering

This introductory course develops a comprehensive understanding of Maxwell's field theory as applied to high-frequency radiation, propagation and circuit phenomena. Topics include radio-frequency (RF) and microwave (MW) propagation modes, transmission line aspects, Smith Chart, scattering parameter analysis, microwave filters, matching networks, power flow relations, unilateral and bilateral amplifier designs, stability analysis, oscillators circuits, mixers and microwave antennas for wireless communication systems. (Prerequisites: ECE 504 or equivalent, undergraduate course in electromagnetic field analysis.)

ECE 5204. Analog Circuits and Intuition

The ability to see the simplicity in a complex design problem is a skill that is not usually taught in engineering classes. Some engineers, when faced with design problems, immediately fill up pages and pages of calculations, or do complex circuit simulations or finite-element analyses. One problem with this approach is that if you get an answer, you do not know if it is correct unless you have an intuitive "feel" for what the answer should be. The application of some simple rules of thumb and design techniques is a possible first step to developing intuition into the behavior of complex electrical systems. This course outlines some ways of thinking about analog circuits and systems that are intended will help to develop intuition and guide design. The lectures are a mixture of instructional sessions covering new background material, and design case studies. (Prerequisites: Undergraduate background in device physics, microelectronics, control systems, electromagnetism)

ECE 523. Power Electronics

The application of electronics to energy conversion and control. Electrical and thermal characteristics of power semiconductor devices—diodes, bipolar transistors and thyristors. Magnetic components. State-space averaging and sampled-data models. Emphasis is placed on circuit techniques. Application examples include dc-dc conversion, controlled rectifiers, high-frequency inverters, resonant converters and excitation of electric machines. (Prerequisites: ECE 3204 and undergraduate courses in modern signal theory and control theory; ECE 504 is recommended.)

ECE 524. Advanced Analog Integrated Circuit Design

This course is an advanced introduction to the design of analog and mixed analog-digital integrated circuits for communication and instrumentation applications. An overview of bipolar and CMOS fabrication processes shows the differences between discrete and integrated circuit design. The bipolar and MOS transistors are reviewed with basic device physics and the development of circuit models in various operating regions. The use of SPICE simulation in the design process will be covered. Integrated amplifier circuits are developed with an emphasis on understanding performance advantages and limitation in such areas as speed, noise and power dissipation. Simple circuits are combined to form the basic functional building blocks such as the op-amp, comparator, voltage reference, etc. These circuit principles will be explored in an IC design project, which may be fabricated in a commercial analog process. Examples of possible topics include sample-and-hold (S/H) amplifier, analog-to-digital (A/D) and digital-to-analog (D/A) converters, phase-locked loop (PLL), voltage-controlled oscillator, phase detector, switched capacitor and continuous-time filters, and sampled current techniques. (Prerequisite: Background in analog circuits both at the transistor and functional block [op-amp, comparator, etc.] level. Also familiarity with techniques such as small-signal modeling and analysis in the s-plane using Laplace transforms. Undergraduate course equivalent background ECE 3204; ECE 4902 helpful but not essential.)

ECE 529. Selected Topics in Electronic System Design

Courses in this group are devoted to the study of advanced topics in electronic system design.

ECE 530/CS 530. High Performance Networks

This course is an in-depth study of the theory, design and performance of high-speed networks. Topics include specifi c high-performance network architectures and protocols and emerging technologies including multimedia networks and quality-of- service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queueing models. (Prerequisite: ECE 506/CS 513.)

ECE 5307. Wireless Access and Localization

This course covers the fundamentals of the evolving wireless localization techniques and their relation with the wireless access infrastructures for Electrical and Computer Engineering, Computer Science or other graduate students interested in this field. The course begins with an explanation of the common ground among wireless access and localization techniques which are principles of waveform transmission in multipath rich urban and indoor areas and the deployment of the infrastructure for wireless networks. This is followed by the fundamentals of received signal strength (RSS) and Time- and Angle-of-arrival (TOA/AOA) based localization techniques, addressing applications, systems, effects of environment, performance bounds and algorithms. The course describes how wireless access methods used in wide, local and personal area networks are related to localization techniques using cellular, UWB, WiFi, and other signals of opportunity as well as mechanical sensors used in different smart phone

Return to Table of Contents

and Robotic platforms. The emphasis on the effects of environment is on the analysis of the effects of multipath on precision of the localization techniques. The emphasis on performance evaluation is on the derivation of Cramer Rao Lower Bound (CRLB). For algorithms, the course describes fingerprinting algorithms used for RSS-based localization and super-resolution, cooperative localization, localization using multi-carrier transmission and localization using multipath diversity as well as Kalman and Particle filtering techniques used for model based localization. Examples of emerging technologies in Body Area Networking and Robotics applications are provided. (Prerequisite: ECE 506, CS 513, or equivalent familiarity with local and wide area networks.)

ECE 531. Principles of Detection and Estimation Theory

Detection of signals in noise, optimum receiver principles, M-ary detection, matched filters, orthogonal signals and representations of random processes. MAP and maximum likelihood estimation. Wiener filtering and Kalman filtering. Channel considerations: prewhitening, fading and diversity combining. (Prerequisites: ECE 502 and ECE 504 or equivalent.)

ECE 5311. Information Theory and Coding

This course introduces the fundamentals of information theory and discusses applications in compression and transmission of data. Measures of information, including entropy, and their properties are derived. The limits of lossless data compression are derived and practical coding schemes approaching the theoretical limits are presented. Lossy data compression tradeoffs are discussed in terms of the rate-distortion framework. The concept of reliable communication through noisy channels (channel capacity) is developed. Techniques for practical channel coding, including block and convolutional codes, are also covered. (Prerequisite: background in probability and random processes such as in ECE502 or equivalent).

ECE 5312. Modern Digital Communications

This course introduces a rigorous analytical treatment of modern digital communication systems, including digital modulation, demodulation, and optimal receiver design. Error performance analysis of these communication systems when operating over either noisy or band-limited channels will be conducted. Advanced topics to be covered include a subset of the following: MIMO, fading channels, multiuser communications, spread spectrum systems, and/or multicarrier transmission. (Prerequisites: An understanding of probability and random processes theory (ECE 502 or equivalent); an understanding of various analog and digital (de)modulation techniques (ECE 3311 or equivalent); familiarity with MATLAB programming.

ECE 5341. Applied Medical Signal Analysis

This course provides a broad introduction to medical signal analysis, particularly tailored to students who have no prior background in physiology or medicine. The course will concentrate on signal analysis of the electrical activity of the human body, providing sufficient physiologic background for study of the relevant organ systems. System-level engineering models of the electrical activity of the heart, skeletal muscles and brain will be presented and actual physiologic signals will be analyzed. Digital signal processing algorithms for analysis of these signals will be studied extensively using MATLAB. Specific signal processing topics may include: use of muscle electrical activity to command powered prostheses and/or guide rehabilitation therapy; design of filters to reject motion artifact, noise and interference; monitoring (e.g., detection and classification) of heart, brain and muscle electrical impulses; and non-invasive estimation of muscle activation level. Students may not receive credit for ECE 5341 and either ECE 443X or ECE 539D. (Prerequisites: Undergraduate (or graduate) course in digital signal processing, experience with MATLAB and a course in probability.)

ECE 537/CS 577. Advanced Computer and Communications Networks

This course covers advanced topics in the theory, design and performance of computer and communication networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queuing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies. (Prerequisite: ECE 506/CS 513 and ECE 581/CS 533.)

ECE 538. Wireless Technologies and Applications

A preview of evolution of wireless information networking standards and technologies for personal, local and six generations of cellular networks, and the distinct role of Wi-Fi in this evolution. Radio Frequency (RF) cloud from wireless devices and embedded big data in them. Models for the behavior of features of RF signals from wireless devices: the Received Signal Strength (RSS), Time-of- Arrival (TOA), Direction of Arrival (DOA), Channel Impulse Response (CIR), and Channel State Information (CSI). Application of models for features of RF signal for design and performance evaluation of mainstream wireless communication technologies: Spread Spectrum, Orthogonal Frequency Division Multiplexing (OFDM), Multiple-Input-Multiple-Output (MIMO) antenna systems, Ultra-Wideband (UWB) and millimeter wave (mmWave) technologies. RSS and TOA features of RF fingerprints of wireless devices for opportunistic positioning and tracking using Wi-Fi and cellular signals. Application of Artificial Intelligent (AI) algorithms and RSS, CIR, and CSI fingerprints of wireless devices to motion and gesture detection, as well as authentication and security. The course is complemented with practical MATLAB oriented assignments, and multi-media supplements. Students will prepare a term paper throughout the course on a topic negotiated with the instructor.

ECE 539. Selected Topics in Communication Theory and Signal Processing

Courses in this group are devoted to the study of advanced topics in in Communication Theory and Signal Processing.

ECE 545/CS 545. Digital Image Processing

See CS 545 course description.

ECE 549. Selected Topics in Control

Courses in this group are devoted to the study of advanced topics in the formulation and solution of theoretical or practical problems in modern control.

ECE 5500. Power System Analysis

This graduate level course examines the principles of Power System Analysis. It will begin with a review of AC circuit analysis. The course will then cover the topics of transmission line parameter calculation, symmetrical component analysis, transformer and load modeling, symmetrical and unsymmetrical fault analysis, power flow, and power systems stability. (Prerequisites: Knowledge of circuit analysis, basic calculus and differential equations, elementary matrix analysis and basic computer programming.)

ECE 5510. Power Quality

This graduate level course provides detailed explanations of the physical mechanisms that control phenomena related to Power Quality. It addresses concepts that underlie harmonic generation and harmonic flow, and the modeling of voltage sags and swells. The effects of such disturbances on equipment (transformers, rotating machines, lamps, relays and converters) performance are studied by means of actual field cases. Frequency response of the grid, resonances and ferroresonances as well as electromagnetic interference are studied. Mitigation methods using advanced transformers connections, static, hybrid and active filters are modeled using real-life examples. Others topics covered are Power Quality measurements in the era of smart grid, Power Quality problems caused by Renewable Generators, and Engineering Economics issues related to Power Quality. (Prerequisites: ECE 5500 Power System Analysis. Also, this course presumes that the student has an understanding of basic electronics.)

ECE 5511. Transients in Power Systems

This graduate level course introduces the student to the effects of electromagnetic transients in distribution systems. Topics include transient analysis, lightning and switching surges, mechanisms of transient generation, insulation coordination, grounding, surge protection devices, and shielding. (Prerequisite: ECE 5500 Power System Analysis)

ECE 5512. Electromechanical Energy Conversion

This graduate level course will further explore alternating current circuits, three phase circuits, basics of electromagnetic field theory, magnetic circuits, inductance, and electromechanical energy conversion. Topics also include ideal transformer, iron-core transformer, voltage regulation, efficiency equivalent circuit, and three phase transformers. Induction machine construction, equivalent circuit, torque speed characteristics, and single phase motors, synchronous machine construction, equivalent circuit, power relationships phasor diagrams, and synchronous motors will be covered. Direct current machine construction, types, efficiency, power flow diagram, and external characteristics will be discussed.

ECE 5520. Power System Protection and Control

This graduate level course seeks to provide an understanding of how interconnected power systems and their components are protected from abnormal events such as faults (short circuits), over-voltages, off-nominal frequency and unbalanced phase conditions. This subject is presented from a theoretical viewpoint, however, many practical examples and applications are included that emphasize the limitations of existing protective equipment. Course content is not specific to any particular manufacturer's equipment.

The course begins with a brief review of power system operation, three-phase system calculations and the representation (modeling) of power system elements. The modeling of current transformers under steady-state and transient conditions is presented with emphasis on the impact on protective devices. A unit on system grounding and its impact on protective device operation are included. Course emphasis then shifts to protective devices and their principles of operation. Both electromechanical and numeric relay designs are covered. The final course segments cover specific applications such as pilot protection of transmission lines, generator protection and transformer protection. (Prerequisite: ECE 5500 Power System Analysis)

ECE 5521. Protective Relaying

This graduate level course is the first of a two course sequence that covers both the principles and practices of power system protective relaying. The course seeks to provide an understanding of how interconnected power systems and their components are protected from abnormal events such as faults (short circuits), over-voltages, off-nominal frequency and unbalanced phase conditions. This subject is presented from a theoretical viewpoint, however, many practical examples are included that emphasize the limitations of existing protective equipment. Course content is not specific to any particular manufacturer's equipment. The course begins with a brief review of the nature of power system operation, power system faults and other abnormal conditions. The nature and objectives of protective relaying are covered next with emphasis on how the power system can be monitored to detect abnormal conditions. The computational tools needed to analyze system operation and apply protective relaying are covered next, including the per-unit system, phasors and symmetrical components. The modeling of current transformers under steady-state and transient conditions is presented with emphasis on the impact on protective devices. A unit on system grounding and its impact on protective device operation is included. Course emphasis then shifts to protective devices and their principles of operation. Both electromechanical and numeric relay designs are covered. (Prerequisite: ECE 5500 Power System Analysis or equivalent background experience is suggested. Familiarity with phasors, derivatives, transfer functions, poles and zeros, block diagram and the notion of feedback with basic understanding power system analysis or similar background is recommended. Note: Credit cannot be awarded for this course if credit has already been received for ECE 5520 Power System Protection and Control.)

ECE 5522. Advanced Applications in Protective Relaying

This graduate level course covers advanced topics in the principles and practices of power system protective relaying. The course seeks to provide an understanding of how protective relays are applied to protect power system components. While the subject is presented from a theoretical viewpoint, many practical examples are included. Examples specific to both new installations and existing, older facilities will be included. Course content is not specific to any particular manufacturer's equipment. The course begins with applications of protective devices to generators. This will include distributed generation as well as wind-turbine and inverter-connected sources. Transformer protection is covered next, including application procedures for older, electromechanical relays as well as modern numeric relay designs. A unit on bus protection is covered next, including all typical high-speed and time backup bus protection schemes. Transmission line and distribution feeder protection is covered in detail including both conventional and communications-assisted schemes. The course ends with a unit on other protection applications such as under frequency load shedding, reclosing and out-of-step relaying. (Prerequisite: ECE 5521 Protective Relaying. Note: Credit cannot be awarded for this course if credit has already been received for ECE 5520 Power System Protection and Control.)

ECE 5523. Power System Dynamics

This graduate level course is concerned with modeling, analyzing and mitigating power system stability and control problems. The course seeks to provide an understanding of the electromechanical dynamics of the interconnected electric power grid. This subject is presented from a theoretical viewpoint; however, many practical examples are included. The course begins with a description of the physics of the power system, frequency regulation during "steady-state" operation, dynamic characteristics of modern power systems, a review of feedback control systems, power system frequency regulation, and a review of protective relaying. This is followed by material on synchronous machine theory and modeling. Simulation of power system dynamic response, small signal stability, transient stability analysis using SIMULINK and effects of non-traditional power sources on systems dynamics will also be covered. Power system stabilizers, load modeling and under frequency load shedding are covered in the final lectures. (Prerequisite: ECE 5500 Power System Analysis and ECE 5511 Transients in Power Systems or equivalent background experience is suggested. Familiarity with the basics of Laplace Transforms, derivatives, transfer functions, poles and zeros, block diagram and the notion of feedback with basic understanding power system analysis topics recommended.)

ECE 5530. Power Distribution

This graduate level course introduces the fundamentals of power distribution systems, apparatus, and practices suited to new and experienced utility distribution engineers. Topics include distribution system designs, transformers and connections, practical aspects of apparatus and protection, principles of device coordination, grounding, voltage control, and power quality. (Prerequisites: Prior courses in magnetism and three-phase circuits. An electric machines course would be recommended.)

ECE 5531. Power System Operation and Planning

This graduate-level course deals with modern operation, control and planning for power systems. Topics include: Characteristics of generating units; Economic Dispatch; Unit Commitment; Effects of the transmission system on power delivery; Optimal Power Flow and Location Marginal Pricing; Power System Security; State Estimation for Power Systems; Power System Reliability Evaluation. Software tools such as MATLAB and power system simulator software will be used both in the classroom and in some homework assignments.

ECE 5532. Distributed and Renewable Power Generation

This course introduces the characteristics and challenges of interconnecting increasing numbers of Distributed Energy Resources (DERs) to the Electric Power System (EPS). Topics include: challenges to distribution and transmission system protection; local voltage control; ride through; optimal interconnection transformer configurations; and practical engineering approaches to maintain system reliability and protection. The current and evolving interconnection standard (IEEE 1547) is included. Prerequisites: Since the course material builds on power system analysis capabilities, including system protection and controls, ECE 5500 Power System Analysis and either ECE

5520 Power System Protection & Control or ECE 5521 Protective Relaying are required. Also, it is recommended that students take this course after completing ECE 5530 Power Distribution.

ECE 5540. Power Transmission

This graduate level course focuses on the theory and current professional practice in problems of electric power transmission. It begins with a review of the theory of AC electric power transmission networks and addresses a range of challenges related to reactive power and voltage control as well as steady-state and transients stability. Students will learn in detail the principles of traditional reactive power compensation (shunt reactors and capacitors); series compensation and modern static reactive compensation like SVC, STATCOM and other Flexible AC Transmission Systems (FACTS) devices. The effects of each of these types of compensation on static and dynamic voltage control, reactive power requirement and steady-state and transient stability problems are covered from theoretical as well as practical aspects. Particular attention is given to the mathematical models and principles of operation of many types of compensation systems. Basic principles of operation and control of High-Voltage DC (HVDC) systems and their impact on steady-state and dynamics of power system will be covered as well. (Prerequisite: ECE 5500 Power System Analysis.)

ECE 5599. Capstone Project Experience in Power Systems

This project-based course integrates power systems engineering theory and practice, and provides the opportunity to apply the skills and knowledge acquired in the Power Systems curriculum. The project is normally conducted in teams of two to four students. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. The projects are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Power Systems profession. (Prerequisites: Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that the student will have completed most or all of the coursework within their plan of study before undertaking the capstone project.)

ECE 559. Selected Topics in Energy Systems

Courses in this group are devoted to the study of advanced topics in energy systems. Typical topics include optimal power flow, probability methods in power systems analysis, surge phenomena, design of electrical apparatus, transient behavior of electric machines and advanced electromechanical energy conversion.

ECE 566. VLSI Design

VLSI Design introduces computer engineers and computer scientists to the techniques, methodologies and issues involved in conceptual and physical design of complex digital integrated circuits. The course presupposes knowledge of computer systems and hardware design such as found in ECE 505, but does not assume detailed knowledge of transistor circuits and physical electronics. (Prerequisite: ECE 505 or equivalent.)

ECE 569. Selected Topics in Solid State

Courses in this group are devoted to the study of advanced topics in solid state, for example: degenerate semiconductors, many-body theory, elastic effects and phonon conduction, and solar cells. To reflect changes in faculty research interests, these courses may be modified or new courses may be added.

ECE 5715. Reconfigurable Computing

This course focused on the principles and applications of using FPGAs for reconfigurable computing. The key feature of reconfigurable computing is its ability to perform computations in customized hardware, while retaining much of the flexibility of a software solution. This course provides an overview of field programmable gate array (FPGA) architecture and technology. It introduces computer-aided design tools for FPGAs including synthesis, timing, placement, and routing. The course emphasizes on the techniques to analyze algorithms and to implement them on the FPGAs. It demonstrates real-time signal and data processing in customized hardware circuits. This course also covers system-on-chip design using the embedded processors inside the FPGAs. Partially reconfiguration and runtime reconfiguration design flow are also included.

ECE 572/CS 514. Advanced Systems Architecture

This course covers techniques such as caching, hierarchical memory, pipelining and parallelism, that are used to enhance the performance of computer systems. It compares and contrasts different approaches to achieving high performance in machines ranging from advanced microprocessors to vector supercomputers (CRAY, CYBER). It also illustrates how these techniques are applied in massively parallel SIMD machines (DAP, Connection Machine). In each case the focus is on the combined hardware /software performance achieved and the interaction between application demands and hardware/software capabilities. (Prerequisites: This course assumes the material covered in ECE 505. The student should also have a background in computer programming and operating systems (CS 502). Familiarity with basic probability and statistics such as ECE 502 or MA 541 is recommended.)

ECE 5720. Modeling and Synthesis of Digital Systems Using Verilog

Automatic design, synthesis, verification, and modeling of complex digital systems with Verilog are the main course objectives. Verilog for modeling existing circuits, as well as Verilog for design and automatic synthesis is discussed. Using Verilog for a design that consists of a hierarchy of components that include controllers, sequential and combinational parts is focused. Design description from transistor level to software interface will be discussed. Students will learn details of hardware of processor architectures and their peripherals. The course discusses module delay adjustments using Verilog path delay and distributed delay mechanisms. Testbench development and assertion verifications will be discussed. Students will learn to simulate verify, synthesize, and program their designs on an Altera development board using advanced Altera FPGAs. (Prerequisite: Undergraduate knowledge of basic logic design concepts. ECE 574 may be substituted for ECE 5720. Students may not receive credit for both ECE 574 and ECE 5720). For students not having the necessary background, online videos will be made available to cover the prerequisites.

ECE 5722. Embedded Core Architectures and Core-based Design

This course introduces the concept of design with embedded components. Embedded processors, IP cores, and bus structures are discussed here. Embedded processor architectures, architectures for arithmetic processors, I/O interfacing modules, memory interfacing, and architectures related to busses and switch fabrics for putting a complete embedded system are discussed here. Topics include RT level design, arithmetic processors, ISA, CPU structure and function, addressing modes, instruction formats, memory system organization, memory mapping and hierarchies, concepts of cache, standard local buses, IO devices, pipelining, memory management, embedded processors, embedded environments, bus and switch fabrics, and embedded system implementation. An example embedded design environment including its configurable cores and processors and its bus structure will be presented in details. The course also includes a number of design projects, including design and simulation of an embedded processor, design of an arithmetic core, and design of a complete embedded system. (Prerequisite: Familiarity with C programming, Undergraduate knowledge of basic logic design concepts, familiarity with a hardware description language). Note: For students not having the necessary background, online videos will be made available to cover the prerequisites.

ECE 5723. Methodologies for System Level Design and Modeling

This course discusses principles, methodologies and tools used for a modern hardware design process. Design flows and hardware languages needed for each stage of the design process are discussed. The use of transaction level modeling (TLM) for dealing with today's complex designs is emphasized. The course starts with a discussion of the evolution of hardware design methodologies, and then discusses the use of C++ for an algorithmic description of hardware. SystemC and its TLM derivative and the role of SystemC in high-level design will be discussed. In addition, RT level interfaces and the use of SystemC for this level of design will be covered. Timed, untimed, and approximately timed TLM models and modeling schemes will be presented. Use of TLM for fast design simulation, design space exploration, and high-level synthesis will be discussed. TLM testing methods and testing of TLM based NoCs will be discussed. The course starts with a complete design project and exercises various parts of this design as methodologies, concepts, and languages are discussed. Specific topics covered are as follows: Levels of abstraction C++ for digital design SystemC RT level and above TLM methodology TLM timing aspects TLM channels TLM channels Mixed level design NoC TLM modeling System testing

ECE 5724. Digital Systems Testing and Testable Design

This course discusses faults and fault modeling, test equipment, test generation for combinational and sequential circuits, fault simulation, memory testing, design for testability, built-in self-test techniques, boundary scan, IEEE 1149.1, and board and SoC test standards. Various fault simulation and ATPG methods including concurrent fault simulation, D-algorithm, and PODEM are discussed. Controllability and observability methods such as SCOAP for testability analysis are discussed. Various full-scan and partial scan methods are described and modeled in Verilog and tested with Verilog testbenches. BIST architectures for processor testing, memory testing and general RT level hardware testing are described, modeled in Verilog and simulated and evaluated for fault coverage. The course uses Verilog testbenches for simulating golden models, developing and evaluating test sets, and for mimicking testers. (Recommended prerequisites: Understanding digital systems and design of combinational and sequential circuits, Understanding a hardware description language (VHDL or Verilog) and the use of these languages for simulation and synthesis.)

ECE 574. Modeling and Synthesis of Digital Systems Using Verilog and VHDL

This is an introductory course on Verilog and VHDL, two standard hardware description languages (HDLs), for students with no background or prior experience with HDLs. In this course we will examine some of the important features of Verilog and VHDL. The course will enable students to design, simulate, model and synthesize digital designs. The dataflow, structural, and behavioral modeling techniques will be discussed and related to how they are used to design combinational and sequential circuits. The use of test benches to exercise and verify the correctness of hardware models will also be described. Course Projects: Course projects will involve the modeling and sysntesis and testing of systems using Xilinx tools. We will be targeting Xilinx FPGA and CPLDs. Students will need to purchase a FPGA or CPLD development board for project assignments. (Other VHDL tools may be used if these are available to the student at their place of employment.) Students will have the choice of completing assignments in either Verilog or VHDL. (Prerequisites: Logic Circuits and experience with programming in a high-level language (such as C or Pascal) and a computer architecture course such as ECE 505.) Students cannot receive credit for both ECE 574 and ECE 5720

ECE/DS 577. Machine Learning in Cybersecurity.

Machine Learning has proven immensely effective in a diverse set of applications. This trend has reached a new high with the application of Deep Learning virtually in any application domain. This course studies the applications of Machine Learning in the sub domain of Cybersecurity by introducing a plethora of case studies including anomaly detection in networks and computing, side-channel analysis, user authentication and biometrics etc. These case studies are discussed in detail in class, and further examples of potential applications of Machine Learning techniques including Deep Learning are outlined. The course has a strong hands-on component, i.e. students are given datasets of specific security applications and are required to perform simulations.

ECE 578/CS 578. Cryptography and Data Security

This course gives a comprehensive introduction to the field of cryptography and data security. The course begins with the introduction of the concepts of data security, where classical algorithms serve as an example. Different attacks on cryptographic systems are classified. Some pseudo-random generators are introduced. The concepts of public and private key cryptography are developed. As important representatives for secret key schemes, DES and IDEA are described. The public key schemes RSA and ElGamal, and systems based on elliptic curves are then developed. Signature algorithms, hash functions, key distribution and identification schemes are treated as advanced topics. Some advanced mathematical algorithms for attacking cryptographic schemes are discussed. Application examples will include a protocol for security in a LAN and a secure smart card system for electronic banking. Special consideration will be given to schemes which are relevant for network environments. For all schemes, implementation aspects and up-to-date security estimations will be discussed. (Prerequisites: Working knowledge of C; an interest in discrete mathematics and algorithms is highly desirable. Students interested in a further study of the underlying mathematics may register for MA 4891 [B term], where topics in modern algebra relevant to cryptography will be treated.)

ECE 579. Selected Topics in Computer Engineering

Courses in this group are devoted to the study of advanced topics in computer engineering such as real-time intelligent systems, VLSI design and high-level languages.

ECE 581/CS 533. Modeling and Performance Evaluation of Network and Computer Systems

Methods and concepts of computer and communication network modeling and system performance evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service and priority systems; work load characterization; performance evaluation problems. (Prerequisites: CS 504 or ECE 502, or equivalent background in probability.)

ECE 5905. Advanced Bipolar Solid State Devices

The operation of the bipolar junction transistor (BJT) will be explored in detail, resulting in thorough understanding of observed phenomena including second-order effects that limit device performance in practical integrated circuit applications. The course begins with a review of semiconductor fundamentals and p-n junction behavior, followed by extension to the BJT, with an emphasis on effects such as temperature dependence of operation parameters, deviations from ideal behavior at high and low voltages and currents, and failure modes such as zener and avalanche breakdown. BJT behavior will be modeled for large and small signals under DC, AC, and transient conditions. Results from theoretical hand-analysis equations will be correlated with model parameters in software tools such as SPICE. Implications of fabrication technology including device scaling in submicron processes will be considered. This course is intended for students pursuing study in either integrated circuit design or device physics. (Prerequisite: undergraduate analog electronics).

Return to Table of Contents

ECE 596A and ECE 596B. Graduate Seminars

The presentations in the graduate seminar series will be of tutorial nature and will be presented by recognized experts in various fields of electrical and computer engineering. All full-time graduate students will be required to take both seminar courses, ECE 596A and ECE 596B, once during their graduate studies in the Electrical and Computer Engineering Department. The course will be given Pass/Fail. (Prerequisite: Graduate standing.)

ECE 597. Independent Study

Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. Can be technical in nature, or a review of electrical and computer engineering history and literature of importance and permanent value. (Prerequisite: B.S. in ECE or equivalent.)

ECE 598. Directed Research

Each student will work under the direct supervision of a member of the department staff on an experimental or theoretical problem which may involve an extensive literature search, experimental procedures and analysis. A comprehensive report in the style of a technical report or paper and an oral presentation are required. (A maximum of two registrations in ECE 598 is permitted.) (Prerequisite: Graduate standing.)

ECE 599. Thesis

ECE 630. Advanced Topics in Signal Processing

The course will cover a set of important topics in signal and image analysis: orthogonal signal decomposition, wavelet transforms, analytic signals, time-frequency estimation, 2D FT, Hankel transform and tomographic reconstruction. In addition, the course will each year have selected current topics in signal processing, e.g., ambiguity functions in RADAR and SONAR, coded waveforms, Fourier based beamforming for 2D arrays and single value decomposition. In place of a final exam, there will be a student project. The course is intended for students working in areas such as image analysis, NDE, ultrasound, audio, speech, RADAR, SONAR and date compression. Signal/image theory and applications will be emphasized over coding; however, Matlab-based modules for self-paced signal/image visualization and manipulation will be part of the course. (Prerequisites: ECE 504 Analysis of Deterministic Signals and Systems, undergraduate course in linear systems theory and vector calculus.)

ECE 673/CS 673. Advanced Cryptography

This course provides deeper insight into areas of cryptography which are of great practical and theoretical importance. The three areas treated are detailed analysis and the implementation of cryptoalgorithms, advanced protocols, and modern attacks against cryptographic schemes. The first part of the lecture focuses on public key algorithms, in particular ElGamal, elliptic curves and Diffie-Hellman key exchange. The underlying theory of Galois fields will be introduced. Implementation of performance security aspects of the algorithms will be looked at. The second part of the course deals with advanced protocols. New schemes for authentication, identification and zero-knowledge proof will be introduced. Some complex protocols for real-world application— such as key distribution in networks and for smart cards—will be introduced and analyzed. The third part will look into state-of-the-art cryptoanalysis (i.e., ways to break cryptosystems). Brute force attacks based on special purpose machines, the baby-step giant-step and the Pohlig-Hellman algorithms will be discussed. (Prerequisites: ECE 578/ CS 578 or equivalent background.)

ECE 699. Ph.D. Dissertation

Return to Table of Contents

Fire Protection Engineering

Faculty

Core FPE Program Faculty

A. Simeoni, Professor and Department Head, Ph.D., University of Corsica; modeling, simulation and experiments of wildfires, heat and mass transfer, fire fighting and land management.

N. A. Dembsey, Professor; Ph.D., University of California at Berkeley; Fire properties of materials and protective clothing via bench-top scale experimentation; compartment fire dynamics via residential scale experimentation, evaluation, development and validation of compartment fire models, performance fire codes, engineering design tools, and engineering forensic tools.

K. A. Notarianni, Associate Professor; Ph.D., Carnegie Mellon University; Fire detection and suppression; high-bay fire protection; fire policy and risk; uncertainty; performance-based design; engineering tools for the fire service.

M. T. Puchovsky, Professor of Practice, Associate Department Head, Industry Liaison; fire engineering design practices, codes and standards development, loss control, life safety code and design, performance-based design and risk analysis, fire investigation and litigation support, fire protection systems.

A. Rangwala, Professor, Ph.D., University of California, San Diego; combustion, flame spread on solid fuels and compartment fire modeling, dust explosions, risk assessment of Liquefied Natural Gas (LNG) transport and storage, industrial fire protection.

Associated FPE Program Faculty

L. Albano, Associate Professor; Ph.D., Massachusetts Institute of Technology; Performance of structural members, elements, and systems at elevated temperatures; structural design for fire conditions; simplified or design office techniques for fire-structure interaction; relationship between building construction systems and fire service safety.

J. Liang, Associate Professor, Ph.D., Brown University, 2004. Nanostructured materials, material processing, materialcharacterization.

Adjunct FPE Faculty

M. Hurley, Adjunct Instructor/Lecturer; Consulting, large unique building design, smoke control systems, detection and alarm, egress from fire.

W. Krein, Adjunct Assistant Professor; Fire Protection Engineering and School of Business; organizational behavior, entrepreneurship, corporate financial management, mergers and acquisitions, consulting, engineering economics, project management.

J. Tubbs, Adjunct Assistant Professor; Consulting, large unique building design, smoke control systems, detection and alarm, egress from fire.

C. Wood, Adjunct Associate Professor; Licensed attorney, fire protection engineering, expert witness testimony, fire modeling and dynamics. Fire investigation, failure analysis of fires and explosions.

FPE Emeritus

R. W. Fitzgerald, Professor Emeritus; Ph.D., University of Connecticut; structural aspects of fire safety, building analysis and design for fire safety, marine fire safety, building codes, real estate development, fire department operations, risk management.

D. A. Lucht, Director Emeritus; building codes and regulatory reform, building fire safety analysis and design, professional practice.

R. Zalosh; Professor Emeritus, Ph.D., Northeastern University; Fire and explosion hazards associated with flammable gases, liquids, and powders. Fire/explosion protection methods and systems designed to deal with these special hazards. Theoretical, experimental, and risk-based engineering tools for addressing these issues.

Research Interests

WPI is a recognized world leader in a wide range of topics in fire protection engineering and related areas. Research is directed toward both theoretical understandings and the development of practical engineering methods. WPI faculty and their students create new knowledge that informs and shapes regulatory policy, building design, product manufacturing, and product performance standards.

Specific capabilities and interests include: fire and material;, combustion and explosion protection; computer modeling; fire performance of structural systems; fire detection and suppression; fire and smoke dynamics; wildland and wildland-urban interface fires; regulatory policy, risk, and engineering framework; and firefighter safety and policy.

Programs of Study

The Department of Fire Protection Engineering serves as a crossroads for bringing together talents from many disciplines to focus on fire and explosion safety problems. The department features formal degree and certificate programs in fire protection engineering, continuing education for the practitioner, and research to uncover new knowledge about fire behavior and fire protection methods.

The fire protection engineering program at WPI adapts previous educational and employment experiences into a cohesive Plan of Study. Consequently, the program is designed to be flexible enough to meet specific and varying student educational objectives. Students can select combinations of major courses, non-major courses, thesis and project topics that will prepare them to proceed in the career directions they desire. The curriculum can be tailored to enhance knowledge and skill in the general practice of fire protection engineering, in fire protection engineering specialties (such as industrial, chemical, energy, design, or testing), or in the more theoretical and research-oriented sphere.

Practicing engineers or others already employed and wishing to advance their technical skills may enter the program as part-time students or take off-campus courses via WPI's Quality Online Courses (see page 8) The master's degree may be completed on a part-time basis in less than two years, depending on the number of courses taken each semester.

WPI offers both master's and doctoral degrees as well as the advanced certificate and graduate certificate in fire protection engineering.

WPI offers combined B.S./M.S. programs for students wishing to complete two degrees in a condensed time frame.

Graduate Certificate

The graduate certificate program in Fire Protection Engineering provides qualified students with an opportunity to further their studies in an advanced field. A completed undergraduate degree in engineering or physical science is the preferred prerequisite for admission. Four courses are selected from a range of offerings in consultation with an academic advisor. Taken together, the courses form a cohesive theme. Options include but are not limited to: Core Concepts in Fire Protection Engineering, Industrial Applications, Hazard and Risk Assessment, Facility and Building Design, Advanced Protection Systems, and Fire Protection Management.

Combined B.S./Master's Program

High school seniors and engineering students in their first three years can apply for this five-year program. This gives high school graduates and others the opportunity to complete the undergraduate degree in a selected field of engineering and the master's degree in fire protection engineering in five years. Holders of bachelor of science degrees in the traditional engineering fields and the master's degree in fire protection engineering enjoy extremely good versatility in the job market.

Master's Program

The M.S. program is a graduate level program in Fire Protection Engineering that is structured to be equally effective for full-time or part-time distance learning study. The M.S. program is a high level graduate program designed to refine critical thinking skills necessary for making you an industry leader.

Ph.D. Program

The Ph.D. degree in the department of Fire Protection Engineering will focus on a program that produces scholars capable of creating new knowledge for the field. Our Ph.D. graduates will function at a high level no matter where they work or go in the profession.

Admission Requirements

High school graduates applying for the Combined B.S./Master's Program must meet normal undergraduate admission criteria. Applicants for the master's or certificate programs should have a B.S. in engineering, engineering technology or the physical sciences. Applicants with no FPE work experience should submit a two-page essay articulating their interest in the field.

Students with science degrees and graduates of some engineering technology disciplines may be required to take selected undergraduate courses to round out their backgrounds.

GRE scores are required for all international students and all Ph.D. applicants.

Degree Requirements

For the M.S.

The program for a master of science in fire protection engineering is flexible and can be tailored to individual student career goals. The fire protection engineering master's degree requires 30 semester hours of credit. Both a thesis and non-thesis option are offered. A 9 credit thesis can replace 9 credits of course work. All M.S. students are required to take 9 units of core classes; FP 521, FP 570, FP 553, and at least one Fire Protection Integration course; FP 571 and/or FP 573. The remaining credits 18 credits are chosen by the student and up to 9 credits can be taken outside of the Fire Protection discipline (with academic advisors approval).

For the Ph.D.

The degree of doctor of philosophy is conferred on candidates in recognition of high scientific attainments and the ability to conduct original research. Ph.D. students must complete a minimum of 90 semester hours of graduate work after the bachelor's degree (or 60 semester hours after the master's). This includes at least 15 semester hours of fire protection engineering course credits and 30 hours of dissertation research.

Doctoral students must successfully complete the fire protection engineering qualifying examination, a research proposal and public seminar, and the dissertation defense.

Graduate Internships

A unique internship program is available to fire protection engineering students, allowing them to gain important clinical experiences in practical engineering and research environments. Students are able to earn income while maintaining their student status. Internships are generally full time for one year and provide the student a chance to try out various areas of practice, generate income, gain knowledge and experience, and make valuable lifetime contacts. No Graduate Credit is earned during an internship. A minimum of 9 graduate credits in FPE must be earned prior to participation in an internship. All Internships must be related to FPE.

Research Laboratories

Fire Science Laboratory

This brand new and exciting laboratory facility supports both fundamental studies and large scale engineering studies, experimentation in fire dynamics, combustion/explosion phenomena, detection, and fire and explosion suppression. The Fire Propagation Apparatus, cone calorimeter, infrared imaging system, phase doppler particle analyzer and room calorimeter are also available, with associated gas analysis and data acquisition systems, making this a truly unique awe-inspiring place to conduct research.

The wet lab area supports water-based fire suppression and demonstration projects.

Serving as both a teaching and research facility, the lab accommodates undergraduate projects as well as graduate students in fire protection engineering, mechanical engineering and related disciplines.

Fire Modeling Laboratory

The Fire Modeling Laboratory specializes in computer applications to fire protection engineering and research. Research activities include computational fluid dynamics modeling of building and vehicle fires, flame spread model development, and building egress modeling.

Combustion Laboratory

The WPI Combusion Lab supports studies of fundamental combustion properties as they relate to fire safety. Experimental set-ups are available for the study of self-heating of coal dust; flammable properties of gasoline containers; cross-correlation velocimetry and the laminar burning velocity of flammable dusts.

Return to Table of Contents

Course Descriptions

All courses are 3 credits unless otherwise noted.

FP 520. Fire Modeling

Modeling of compartment fire behavior is studied through the use and application of two types of models: zone and field. The zone model studied is a student developed model. The field model studied is FDS. Focus on in-depth understanding of each of these models is the primary objective in terms of needed input, equations solved, interpretation of output and limitations. A working student model is required for successful completion of the course. Basic computational ability is assumed. Basic numerical methods are used and can be learned during the course via independent study. (Prerequisite: FP 521 or permission of the instructor.)

FP 521. Fire Dynamics I

This course introduces students to fundamentals of fire and combustion and is intended to serve as the first exposure to fire dynamics phenomena. The course includes fundamental topics in fire and combustion such as thermodynamics of combustion, fire chemistry, premixed and diffusion flames, solid burning, ignition, plumes, heat release rate curves, and flame spread. These topics are then used to develop the basis for introducing compartment fire behavior, pre- and post-flashover conditions and zone modeling. Basic computational ability is assumed. Basic numerical methods are used and can be learned during the course via independent study. (Prerequisites: Undergraduate chemistry, thermodynamics or physical chemistry, fluid mechanics and heat transfer.)

FP 553. Fire Protection Systems

This course provides an introduction to automatically activated fire suppression and detection systems. A general overview is presented of relevant physical and chemical phenomena, and commonly used hardware in automatic sprinkler, gaseous agent, foam and dry chemical systems. Typical contemporary installations and current installation and approval standards are reviewed. (Prerequisites: Undergraduate courses in chemistry, fluid mechanics and either thermodynamics or physical chemistry.)

FP 554. Advanced Fire Suppression

Advanced topics in suppression systems analysis and design are discussed with an aim toward developing a performance-based understanding of suppression technology. Automatic sprinkler systems are covered from the standpoint of predicting actuation times, reviewing numerical methods for hydraulic analyses of pipe flow networks and understanding the phenomenology involved in water spray suppression. Special suppression systems are covered from the standpoint of two-phase and non-Newtonian pipe flow and simulations of suppression agent discharge and mixing in an enclosure.

FP 555. Detection, Alarm and Smoke Control

Principles of fire detection using flame, heat and smoke detector technology are described. Fire alarm technology and the electrical interface with fire/smoke detectors are reviewed in the context of contemporary equipment and installation standards. Smoke control systems based on buoyancy and HVAC principles are studied in the context of building smoke control for survivability and safe egress. (Recommended courses to be taken prior to, or concurrently: FP 521.)

FP 570. Building Fire Safety I

This course focuses on the presentation of qualitative and quantitative means for firesafety analysis in buildings. Fire test methods, fire and building codes and standards of practice are reviewed in the context of a systematic review of firesafety in proposed and existing structures.

FP 571. Performance-Based Design

This course covers practical applications of fire protection engineering principles to the design of buildings. Both compartmented and non-compartmented buildings will be designed for criteria of life safety, property protection, continuity of operations, operational management and cost. Modern analytical tools as well as traditional codes and standards are utilized. Interaction with architects and code officials, and an awareness of other factors in the building design process are incorporated through design exercises and a design studio. (Prerequisites: FP 553, FP 521 and FP 570, or special permission of the instructor.)

FP 572. Failure Analysis

Development of fire investigation and reconstruction as a basis for evaluating and improving fire-safety design. Accident investigation theory and failure analysis techniques such as fault trees and event sequences are presented. Fire dynamics and computer modeling are applied to assess possible fire scenarios and the effectiveness of fire protection measures. The product liability aspects of failure analysis are presented. Topics include products liability law, use of standard test methods, warnings and safe product design. Application of course materials is developed through projects involving actual case studies.

FP 573. Industrial Fire Protection

Principles of fire dynamics, heat transfer and thermodynamics are combined with a general knowledge of automatic detection and suppression systems to analyze fire protection requirements for generic industrial hazards. Topics covered include safe separation distances, plant layout, hazard isolation, smoke control, warehouse storage, and flammable liquid processing and storage. Historic industrial fires influencing current practice on these topics are also discussed. (Prerequisites: FP 553, FP 521 or special permission of the instructor.)

FP 575. Explosion Protection

Principles of combustion explosions are taught along with explosion hazard and protection applications. Topics include a review of flammability limit concentrations for flammable gases and dusts; thermochemical equilibrium calculations of adiabatic closed-vessel deflagration pressures, and detonation pressures and velocities; pressure development as a function of time for closed vessels and vented enclosures; the current status of explosion suppression technology; and vapor cloud explosion hazards.

FP 580. Special Problems

Individual or group studies on any topic relating to fire protection may be selected by the student and approved by the faculty member who supervises the work. Examples include:

- Business Practices
- Combustion
- People in Fires
- Fire Dynamics II
- Fire and Materials
- Forensic Techniques
- Complex Decision Making

FP 590. Thesis

Research study at the M.S. level.

FP 690. Ph.D. Dissertation

Return to Table of Contents

Interactive Media & Game Development

Faculty

E. O. Agu, Professor; Ph.D., University of Massachusetts, 2001. Computer graphics, wireless networking, and mobile computing.

S. Barton, Associate Professor; Ph.D. University of Virginia, 2012. Human-robot interaction in music composition and performance, design of robotic musical instruments, music perception and cognition, audio production.

S. Bhada, Assistant Professor, Systems Engineering; Ph.D., University of Alabama. Modeling based systems engineering (MBSE), engineering education and team mental models.

F. J. Chery, Assistant Teaching Professor; M.F.A., FullSail University, 2010. 3D Rigging/technical art, digital sculpting, futurism, expressive game mechanics, motion capture, photogrammetry.

K. Ching, Assistant Professor; Ph.D., Massachusetts Institute of Technology; entrepreneurial strategy, economics of science and innovation, science and innovation policy, digitization, data science.

M. L. Claypool, Professor; Ph.D., University of Minnesota, 1997. Distributed systems, networking, multimedia and online games.

J. deWinter, Professor; Ph.D., University of Arizona, 2008. Japanese game studies, experience design, virtual and augmented reality, games for social justice, production management and entrepreneurship in games.

E. Gutierrez, Assistant Professor; M.F.A., Academy of Art University, 2007. 2D/3D animation, concept art, digital painting, character design, short film production.

L. Harrison, Assistant Professor, Ph.D., University of North Carolina at Charlotte, 2013. Information visualization, visual analytics, perception and cognition of data, modeling and quantitative analysis of human behavior, statistical literacy.

N. T. Heffernan, Associate Professor; Ph.D., Carnegie Mellon University, 2001. Educational data mining, learning sciences and technology.

V. J. Manzo, Associate Professor; Ph.D. Temple University, 2012. Interactive music systems, algorithmic and traditional composition, electric guitar performance and innovation, music theory, music education.

B. J. Moriarty, Professor of Practice; M.Ed., Framingham State University, 2014. Digital games and culture, virtual communities, interactive fiction.

D. M. O'Donnell, Teaching Professor; M.F.A., Brandeis University, 1990. Game and level design, narrative, impact of new media on society, board game design, escape room design.

E. Ottmar, Assistant Professor, Ph.D., University of Virginia, 2011. Theories in developmental, educational, and cognitive psychology, and mathematics and teacher education.

C. D. Roberts, Assistant Professor; Ph.D., UC Santa Barbara, 2014. Computer music, creative coding, live coding, large-scale virtual reality, audiovisual authoring.

J. Rosenstock, Associate Professor; M.F.A., School of the Art Institute of Chicago, 2004. Multimedia performance, interactive installation art, electronic instrument design, light art, BioArt.

G. M. Smith, Associate Professor; Ph.D., UC Santa Cruz, 2012. Computational creativity, games and social justice, tangible computing, computer science education, computational craft, procedural generation.

R. P. H. Sutter, Senior Instructor/Lecturer; B.S., New England Institute of Art, 2010. 3D animation, digital sculpting/character creation, games, augmented reality, traditional animation and art.

K. Zizza, Instructor; Digital audio, game design.

A full listing can be found here: https://www.wpi.edu/academics/departments/interactive-media-game-development/faculty-staff

Annual Progress Review Milestone

In addition to the milestones specific to each degree, all IMGD graduate students must participate in an annual progress review conducted by the program. Students submit a report describing the work they have completed that year and reflection on their progress. A faculty committee reviews each report, discusses student progress, and makes a decision about student continuation in the program. There are three potential recommendation outcomes from this review milestone: a) satisfactory progress, b) program warning, and c) program dismissal. If a student receives a warning, then they will receive constructive feedback on how to improve their performance. If the committee recommends the student for dismissal, they enter WPI's academic dismissal process as described in the "Academic Standards" section of this catalog.

Master of Science in Interactive Media & Game Development

Program of Study

The Master of Science in Interactive Media & Game Development (IMGD) is designed for those interested in the design of immersive, interactive environments. The intended audience includes college graduates looking for continued education in interactive media, game-industry professionals looking to assume leadership roles, professionals from other fields retooling for the game industry, and those seeking scholarship in interactive media. Graduate students in IMGD: 1) take core courses that provide a base of knowledge relevant to the design of interactive media; 2) select courses from Technical, Serious Games, or Management Focus areas that enable tailoring the degree to suit interests and career goals; and 3) design, develop, and evaluate a substantial group project and/or undertake a thesis with novel scholarship as a capstone experience.

Return to Table of Contents

Graduates with an IMGD graduate degree will be qualified to pursue a diverse range of careers in the interactive media, computer games, or related industries, becoming producers, designers, academics, or project leaders in specific subfields such as technology, art, or design.

Admission Requirements

- Statement of purpose that details:
  - the student's goals, and
  - the student's previous industry or academic experiences.
- Proof of a four-year degree. Applicants who are not participating in the B.S./M.S. program must submit a final transcript showing that they have completed a bachelor's degree or its equivalent before enrolling in the M.S. program.
- Three letters of recommendation from individuals who can comment on the student's qualification for pursuing graduate study in IMGD.
- Applicants may submit other material supporting their application, such as a portfolio of their work.

More information on admissions can be found here: https://www.wpi.edu/academics/departments/interactive-media-game-development/resources/admissions-portfolio-guidelines

Degree Requirements

IMGD M.S. students undertake a Game Design Studio course (3 credit hours), a core course relevant to their focus area (3 credit hours) and two other core courses (6 credit hours) covering various aspects of design, supplemented by two courses (6 credit hours) supporting a focus area (Serious Games, Technical, or Production Management), and one elective course (3 credit hours). Each student is required to complete either a Master's thesis (a systematic approach to addressing an identified research question, typically done individually) or a Master's project (a substantial development effort that follows a production plan to implement a design vision, typically done in teams) to complete the degree requirements (9 credit hours).

Game Design Studio (3 credits)

IMGD 5000. Game Design Studio

Focus Area Core Course (3 credit hours)

Technical: IMGD 5100
Serious Games: IMGD 5500
Production Management: IMGD 5400

Core Course Electives (6 credit hours)

IMGD 5100 Tangible and Embodied Interaction

IMGD 5200 History and Future of Immersive and Interactive Media

IMGD 5300 Design of Interactive Experiences

IMGD 5400 Production Management for Interactive Media

IMGD 5500 Serious and Applied Games

IMGD 5600 Multidisciplinary Research Methods in Computational Media

Focus Courses (6 credits)

Technical Focus, or

Serious Games Focus, or

Management Focus

(see details at https://www.wpi.edu/academics/study/interactive-media-game-development-ms

Elective Course (3 credits)

Selected from the courses in the Core and Focus areas, or

IMGD 5099 (Special Topics in IMGD).

Thesis/Project (9 credits)

The IMGD program also offers a B.S./M.S. program for current IMGD undergraduate students. Students enrolled in this program may count up to 12 credit hours of specific undergraduate courses towards both their B.S. and M.S. degrees.

Details on the degree requirements for both M.S. and B.S./M.S. students can be found here: http://imgd.wpi.edu/gradrequirements.html

MFA in Interactive Media and Game Design

Program Goals and Objectives

The Master of Fine Arts (MFA) degree is a terminal degree that focuses on the development and establishment of a creative practice and voice. After completing the MFA in Interactive Media and Game Design, students will be able to:

1. Contextualize their work in the history of their chosen medium as well as modern practice.
2. Respond to and deliver critique effectively.
3. Lead projects and collaborate effectively.
4. Create works that express their unique voice within their chosen medium.
5. Maintain a professional portfolio that effectively showcases their work.
6. Articulate their path for professional and artistic growth after graduation.

Curriculum

The MFA requires 51 credit hours, spread across Design Studio (12 credit hours), Core Coursework (21 credit hours), a professionalization requirement (6 credit hours), an elective (3 credit hours), and a thesis project (9 credit hours).

Design Studio (12 credits)

IMGD 5000. IMGD Studio

*IMGD Studio is taken every semester of the three year program.

Core Courses (21 credits)

IMGD 5010. IMGD Fundamentals*

IMGD 5100. Tangible and Embodied Interaction

IMGD 5200. History and Future of Immersive and Interactive Media

IMGD 5300. Design of Interactive Experiences

IMGD 5400. Production Management for Interactive Media

IMGD 5500. Serious and Applied Games

*This is a rotating special topics course. Students must take two different versions of this course during their degree.

Professionalization (6 credits)

IMGD 6000. IMGD Colloquium

IMGD 6001. IMGD Career Colloquium

*One IMGD Colloquium course is taken every year of the three year program. IMGD 6001 should be taken in the student's final year.

Three credits of graduate internship OR Completion of a Teaching Certificate

Elective Courses (3 credits)

Students may choose any graduate level IMGD course, any 4000-level IMGD course (for two credits), or an elective course from the MS electives list.

Project (9 credits)

All students are required to complete an interactive or game project and show the game in a public forum open for public engagement and critique. The student's advisor is the instructor of record for these credits. The project must be approved by a committee of three faculty, comprised of the student's advisor and two additional members drawn from the IMGD faculty. Projects must be conducted by individuals; team-based projects are not permitted for the MFA.

Admissions Requirements

In addition to the general requirements for admission into any graduate program at WPI https://www.wpi.edu/admissions/graduate/how-to-apply, applicants must submit the following credentials for an application to be complete:

1. Statement of purpose that details:
   a. the student's goals, and
   b. the student's previous industry or academic experiences.
2. An Artist's Statement that describes the student's artistic identity and vision
3. Portfolio

The range of potential IMGD MFA projects is broad--from digital games to interactive theater--and, as such, the range of skills required to achieve those projects is highly variable. Prospective students will be evaluated based on the admission committee's judgment of their likelihood to succeed in the program given their stated goals and prior experience.

Exit Requirements

1. Capstone project
2. Public presentation of capstone project
3. Portfolio (as a requirement of IMGD 6001, Job Colloquium)

PhD in Computational Media

Program Goals and Objectives

Doctor of Philosophy in Computational Media (CM) candidates conduct advanced study in areas of humanistic expression voiced through computational means. The program recognizes play and art as fundamentally important aspects of human experience that can be shaped in compelling ways via technological tools and methods. Conversely, computational research can find new trajectories via the exploration of art and play. Individual paths include the study and design of human-computer interfaces, games and game engines, narratives, artificial intelligence, creativity, communication, and visual and sonic media. As these journeys are inherently interdisciplinary, students will find opportunities to explore related fields including computer science, data science, electrical and computer engineering, systems dynamics, robotics engineering, business, and psychology.

After completing the PhD in Computational Media, students will be able to:

1. Conduct scholarly research on a professional level by articulating motivating research questions, comprehensively reviewing relevant literature, and implementing appropriate research methodologies.
2. Design and develop a portfolio of artifacts that expresses:
   a. Proficiency in both creative and technical practices.
   b. Expert knowledge of the prior art that defines a context at the intersection of human creativity and computation.
   c. Understanding of the opportunities and requirements for novel contribution to a canon that defines a scholarly field.
3. Explain how computational means reflect, inspire, and shape human creativity in the generation of new media.
4. Understand the benefits of interdisciplinary research and methodologies for conducting research in interdisciplinary teams.
5. Disseminate research in the venues that are most relevant and impactful and, in doing so, connect to communities that value their work.

Curriculum

The PhD requires 60 credit hours following the completion of a master's degree. These 60 credit hours are split between coursework (30 credits) and research (30 credits). All students are required to take 15 credits in the CM Core, fulfilling the following requirements:

- IMGD 5000, IMGD Studio.
- IMGD 5600, Multidisciplinary Research Methods in Computational Media.
- IMGD 5200, History and Future of Immersive and Interactive Media.
- IMGD 5100, Tangible and Embodied Interaction.
- IMGD 5010, IMGD Fundamentals.*

* This is a rotating topics course. Students must take one versions of this course during their degree, which should be on a topic outside their prior academic preparation.

The remaining 15 credits should be fulfilled through open electives in areas related to CM. Students should work in collaboration with their advisor to choose these electives. In acknowledgment of the highly interdisciplinary nature of Computational Media, students are advised to choose courses from across the graduate catalog. Undergraduate courses count for 2 graduate credits and may be taken with approval of the student's advisor.

Students who enter the PhD in Computational Media via the IMGD MS program must fulfill any remaining CM Core courses that they have not already taken, and then take the remainder of their coursework requirement as open electives (including independent study).

Additional Degree Requirements

There are four major research milestones for PhD students, spread across the degree:

Paper requirement. The student should show evidence of having contributed to publishable work (e.g. primary authorship on a conference paper or journal article in a reputable venue). This milestone should be achieved by the end of year two, and must be approved by the student's thesis advisor and the IMGD graduate committee.

PhD qualifying exam. No later than the end of the student's fifth full semester in the PhD program, the student should complete a qualifying exam set by a committee of three faculty including the student's advisor. This committee should be the same as intended for their thesis proposal except for the external member. At least two members of this committee must hold a PhD. For their qualifying exam, the student defines their own research area in which they intend to become an expert, and sequentially complete the following milestones related to that area:

a) Conduct a thorough literature review, identifying themes and major research questions in that area. The literature list is initially proposed by the student, and modified then approved by the faculty committee.

b) A response to three questions, each posed by the faculty committee, that allows the student an opportunity to analyze, critique, and connect the ideas, themes and questions resulting from the literature review.
   a. At least one of these questions must be analytical in nature, in which the student responds by writing an essay that draws upon the literature in their area.
   b. At least one of the questions must be a prompt for making an artifact relevant to the candidate's area (e.g. a technical system implementation or a game prototype).
   c. Students will have two weeks to complete this requirement.

c) Give a 45 minute oral presentation that teaches about the core area of study the student has identified.

d) Design a syllabus for a graduate level special topics course that teaches about the identified area, to be approved by the faculty committee.

If the committee finds that a student did not successfully pass either (b) or (c), the student may make one additional attempt to pass per step. If the committee judges a repeated attempt to have failed, the student will be asked to leave the program.

Advancement to PhD candidacy. By the beginning of year four, the student should have assembled their PhD committee and complete their PhD proposal. This committee may change between the candidate's qualifying exam and PhD proposal; however, after advancing to candidacy changing a PhD committee requires approval by the IMGD graduate steering committee. The PhD committee must have the following general composition:

- the student's advisor,
- two faculty members internal to IMGD/CS/HUA,
- one external committee member, who may be either a tenure-track faculty member at WPI who is external to IMGD/CS/HUA, a faculty member at a different university, or a researcher in industry with equivalent qualifications to a tenure-track faculty member as judged by the IMGD graduate committee.

At least two members of the thesis committee must hold a PhD.

The thesis proposal is delivered as a written document, and also presented in a public forum followed by oral examination in a private session open only to the student and committee. The potential outcomes from the thesis proposal are: "pass", "pass with revisions", and "fail and re-propose". This is decided by committee vote following deliberations, for which the student is not present. If revisions are required, then they must be submitted in writing to the committee, but the student is not required to re-present their proposal.

Dissertation defense. The student must defend their written dissertation through an oral presentation that is open to the public, followed by a private defense with the committee members. Potential outcomes from the committee vote on a student's defense are: "pass with minor revisions", "pass with major revisions", and "fail and re-defend". Revisions are changes to the written dissertation. Minor revisions can be approved by the advisor alone, major revisions require the full committee to approve, and "fail and re-defend" requires the student to make substantial revisions to the research and to present again.

Admissions Requirements

In addition to the general requirements for admission into any graduate program at WPI (https://www.wpi.edu/admissions/graduate/how-to-apply), applicants must submit the following credentials for an application to be complete:

1. Statement of purpose that details:
   a. the student's goals, and
   b. the student's previous industry or academic experiences.
2. Portfolio or Work Sample

Students who apply to the CM PhD who do not yet have a master's degree should first enter the MS in IMGD. Students whose master's degree is in an area that is distant from IMGD may be encouraged by the graduate committee to take additional coursework as part of their PhD.

Facilities/Research Labs /Research Centers

- IMGD Lab. 27-seat teaching/research lab.
- Zoo Lab. 25-seat teaching/research lab.
- Digital Art Studio. Work space for both digital and traditional art.
- Performance Evaluation of Distributed Systems (PEDS) Lab. Design and analysis of distributed systems, with a special focus on the performance on networking.
- Mixed Reality Development Group. Design, implementation, and analysis of virtual and augmented reality systems.
- Music, Perception, and Robotics Lab. Musical creativity, perception and cognition, expressive robotic and mechatronic systems.

Course Descriptions

All courses are 3 credits unless otherwise noted.

IMGD 5000. IMGD Studio

This is a "studio" course in which the instructor will guide and mentor the students on individual and/or joint projects. The focus of the course will be on the design of interactive media and games, with the students designing (and optionally implementing) one or more games or interactive experiences. There will also be readings and discussion of design theory as it relates to student projects. This course can be taken for M.S. credit twice if desired.

IMGD 5010. IMGD Fundamentals

In this course, students learn foundational theories and gain foundational skills in interactive media, game development, and computational media targeted at the graduate level, for students with a prior undergraduate background in related fields. Students will read about contemporary challenges in application of these fundamentals to IMGD-related projects, and build disciplinary knowledge and practices necessary for the creation of interactive media and/or games. Topics covered in this course alternate each year based on instructor. Different instantiations of the course cover topics in programming and computing in media contexts (computation studio), art asset conceptualization, creation, and iteration (visual arts studio), audio remixing and composition methods (audio lab), and narrative in interactive contexts (narrative design lab). This course will be offered each year, with topic defined by the faculty member teaching it.

Return to Table of Contents

IMGD 5100. Tangible and Embodied Interaction

Tangible and embodied interaction sees humans at the center of the designed experience. A number of systems continue to emerge to immerse the body into a system, such as virtual reality, augmented reality, mixed reality, alternative controls in the forms of guitars or cockpits, sewing machines, mobile phones and technologies, and even more. Through a combination of traditional lecture, literature review, and hands-on work, students will learn to critically evaluate different alternatives, build prototype systems, and design comparative evaluations to test the effectiveness of various techniques.
Students will be expected to implement several techniques as part of this course.

IMGD 5200. History and Future of Immersive and Interactive Media

This course will familiarize students with the history of the development, deployment, commercialization, and evolution of immersive and active media. The lesson plan will cover a broad range of enabling technologies, such as geometric perspective drawing, pre-20th-century panoramic displays, photography and the stereoscope, sound recording and reproduction, motion pictures, radio and television, the planetarium, immersive and 3-dimensional cinema, and special attraction venues, with a particular focus on digital games. Current trends and future directions will also be considered. Students will attend seminars and lectures, read and discuss texts on media history and aesthetics, and write an original research paper. Midterm and final exams test students' knowledge and understanding of important events and developments. A student may not receive credit for both IMGD 5200 and IMGD 4200. (Prerequisites: An understanding of dominant themes and genres in video games)

IMGD 5300. Design of Interactive Experiences

This course will introduce students to the theories of design, the purpose of which is to guide students in articulating a design vision that can then be implemented in an interactive experience such as a computer game or an art installation. The design elements addressed in this course are as follows: narrative, visual, sound, spatial, challenges and objectives, and characters. This course also emphasizes the communicative strategies needed to sell other people on a design in order to enter production, convince investors, and engage users. Students will be required to design an environment that is populated in a meaningful way that is dependant on the purpose of their visions. They will provide mock-ups of this environment that they must present to their stakeholders - the professor and peers - and finally create prototypes that help them sell their design idea. Throughout the class, students will be writing their designs in professional genres, presenting their designs to the class (often called a pitch), and discuss the theories and practices of design during in-class meetings. (Prerequisites: A course on game design, or equivalent work experience)

IMGD 5400. Production Management for Interactive Media

This course focuses on the process of creating a set of documents encompassing the design and vision of a piece of interactive media, methods for structuring the implementation of the design, and tools for successfully managing the project. Students will analyze different types of design documents, focusing on form and purpose while also considering audience and publication medium. Students will write design documents, give peer feedback, and revise their own documents based on feedback received. In order to see their design transform from document to product, students will study different project management methods and employ them, defining in detail discrete components, timelines, milestones, players and their responsibilities, and status reports to stakeholders. Tools common to managing interactive media projects (e.g., source-code revision control, asset management, scheduling) will be used throughout the process. (Prerequisites: Experience working on development projects)

IMGD 5500. Serious and Applied Games

This course covers methods and analysis for designing, implementing, and assessing games in serious, applied contexts. Often called "serious games" or "applied games", these are game-based media that teach, engage with social issues, aim to increase empathy, or affect behavioral change. Students will read contemporary literature in the field of serious and applied games, design and implement their own games, and measure the effectiveness of those games in achieving educational or motivational goals.

IMGD 5600. Multidisciplinary Research Methods in Computational Media

This course covers research methods used in computational and interactive media. As an interdisciplinary field, computational media relies on multiple research methods, such as qualitative, quantitative, design-based research, iterative design methodology, player and user-testing, historical and cultural research methods, computational reasoning, data analysis, and visual analysis. Students will read broadly in research methodologies and discuss applicability and adaptability for particular processes and research questions.

IMGD 6000. IMGD Colloquium

(1 credit) This course introduces students to the state of the field and current research in the program. Both faculty and external visitors to IMGD will speak at the colloquia on contemporary and emergent topics in interactive media and game design. This course is taken with a pass/fail grading option.

IMGD 6001. IMGD Career Colloquium

(1 credit) This course meets weekly to professionalize students preparing for the academic or artistic job markets. Topics will include goal setting, application materials, practice interviews, practice teaching demonstrations, portfolio development, and other materials as needed. This course is taken with a pass/fail grading option.

IMGD 699. PhD Dissertation. (credit varies)

Can be taken any time after passing the qualifying exam, and is required in the last semester for writing and defending the PhD dissertation. (Prerequisite: Consent of advisor).

IMGD 799. PhD Qualifying Examination. (0 credits)

Students are required to complete a qualifying examination process before work can begin on PhD thesis research. This examination must be approved by a committee of faculty.

Return to Table of Contents

Interdisciplinary Programs

New fields of research and study that combine traditional fields in innovative ways are constantly evolving. In response to this, WPI encourages the formation of interdisciplinary graduate programs to meet new professional needs or the special interests of particular students.

Individually Designed Ph.D. Degrees

Students may design their own interdisciplinary Ph.D. program in consultation with faculty members relevant to the proposed project.

Individually designed Ph.D. degrees are initiated by a student with the support of groups of at least three full-time faculty members who share a common interest in a cross-disciplinary field. A sponsoring group submits to the Committee on Graduate Studies and Research (CGSR) a proposal for an individually designed, interdisciplinary degree, together with all the details of the degree requirements and the credentials of the members of the sponsoring group. At least one member of the group must be from a department or program currently authorized to award the doctorate. Typically the student is assigned a department that matches the department of the primary advisor.

If the CGSR approves the proposal, the sponsoring group serves in place of a department in the administration of the approved interdisciplinary program. Administrative duties include admitting and advising students, preparing and conducting examinations, and certifying the fulfillment of degree requirements.

In addition to the general requirements established by WPI for an Individually designed doctoral degree, applicants must pass a qualifying examination. This examination will test the basic knowledge and understanding of the student in the disciplines covered by the research as is normally expected of degree holders in the disciplines. It should be administered after completion of 18 credits but before completion of 36 credits of work in the interdisciplinary Ph.D. program. The examination will be administered by a committee of no less than three members, approved by CGSR, representing the disciplines covered by the research. Students are allowed at most two attempts at passing the examination, and may take a maximum of 18 credits prior to passage.

Individually Designed Master's Degrees

Individually designed master's degrees require at least 30 credits beyond the bachelor's degree. They may also include a thesis or project requirement. Proposals for such degrees are initiated by a student with the support of groups of at least two faculty members from different academic departments who share a common interest in a cross-disciplinary field. The sponsoring group submits a proposal for an individually designed, interdisciplinary degree to the Committee on Graduate Studies & Research (CGSR) that includes the details of a program of study and the credentials of the members of the group. At least one member of the group must be from a department or program currently authorized to award the master's degree. No more than half of the total academic credit may be taken in any one department. The CGSR may request additional input from the sponsors or appropriate departments. If the CGSR approves the proposal, the sponsoring group serves in place of a department in administration of the approved program. Typically the student is assigned a department that matches the department of the primary advisor.

Interdisciplinary graduate certificate and degree programs that are established and currently accepting students are: Aerospace Engineering, Bioinformatics and Computational Biology, Bioscience Management, Data Science, Information Security Management, Interactive Media & Game Development, Learning Sciences & Technologies, Materials Systems Engineering, Nuclear Science & Engineering, Power Systems Engineering, Power Systems Management, Robotics Engineering, Robotics Engineering Management, System Dynamics, System Dynamics and Innovation Management, Systems Engineering, Systems Modeling, and Systems Thinking.

Interdisciplinary Courses

ID 500. Responsible Conduct of Research

(0 credits; pass/fail grading)

The purpose of this zero credit course is to familiarize pre-doctoral and postdoctoral trainees with basic ethical issues in research confronting scientists and engineers. The course includes lectures and student-led discussion sessions on topics such as experimental design best practices, research involving animal subjects, authorship, and research misconduct. Student learning will be assessed through in-class formative assessments as well as small group presentations during the discussion sessions. The course is recommended for all graduate students and postdocs who are engaged in research and is offered annually in C-term.

ID 527. Fundamentals of Scientific Teaching and Pedagogy

(0 credits; pass/fail grading)

The purpose of this zero credit course is to bolster teaching proficiency for pre-doctoral and post-doctoral trainees through in depth and interactive sessions on the science behind student learning, scientific teaching, assessments and rubrics, active learning, project based learning, inclusive learning environments, teaching philosophies, technology in the classroom, and course design. Participants will learn through both lecture and practicum sessions each week, and will work in small groups to develop a short teachable unit incorporating the techniques learned throughout the course, which they will ultimately present at the conclusion of the series. Students will also develop a statement of teaching philosophy during the course and receive feedback on the statement. The course is recommended for all graduate students and postdocs who are pursuing careers that will entail teaching in higher education as well as those interested in learning the fundamentals of pedagogy and effective teaching strategies. The course is offered annually each summer.

WR 593. Special Topics in Writing and Communication

The purpose of this course is to offer opportunities to graduate students to explore and develop their skills in writing and communication. The course content and format vary to suit the interests and needs of the faculty and students. Topics may include technical writing, science writing, health communication, public understanding of science, design of communication, and communicating risk and ethics in technology design. Contact the Humanities and Arts Department or the Professional Writing Program for current topic offerings.

Return to Table of Contents

Bioscience Management

Faculty

Faculty hold a full time position in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

Program of Study

WPI offers graduate levels studies in the field of Bioscience Management leading to the Master of Science. This program is designed to offer both business and science education thus meeting an educational need in the life sciences and bioresearch fields. This degree is applicable for students seeking employment in pharmaceutical, biotechnology, and biomedical device companies. This program helps science professionals advance their science knowledgebase and also helps them build the necessary administrative infrastructure for their field.

Admissions Requirements

Admission for the Master's degree is consistent with the admission requirements listed in the Graduate Catalog for a Master of Science degree. Appropriate undergraduate bachelor's degree majors include but are not limited to life science, management, engineering, and computer science. Students with other backgrounds may be considered with the approval of the program administrator. Students need a working knowledge of basic biotechnology, biochemistry, cell biology, and chemistry.

Certificates

Graduate Certificate in Life Science Management

This certificate program is designed to meet the needs of a variety of corporations and individuals who are interested in honing advanced technical and business skill sets necessary to fill leadership roles within the life science industry. Inherent in the program of study is sufficient course selection flexibility for students to, if desired and admitted, be able to continue their graduate studies and earn an MS degree in Biotechnology, Biochemistry, or Bioscience Management, depending on student interest and background. The program of study requires 12 credits of coursework chosen from amongst our life science and management course offerings:

- At least six credits must be chosen from courses thematically-related to the life sciences and may include those with a prefix of BB, BCB, CH, or other approved department by the CBC faculty administrator (for ex. BME, CHE)
- At least three credits of management coursework, typically chosen from amongst the following list of courses:
  - BUS 546 Managing Technological Innovation
  - ETR 593 Technology Commercialization
  - MIS 576 Project Management
  - OBC 505 Teaming and Organizing for Innovation
  - OBC 506 The Heart of Leadership: Power, Reflection, and Interpersonal Skills
  - OBC 533 Negotiations
  - OBC 537 Leading Change
  - OIE 542 Risk Management and Decision Analysis
  - OIE 548 Productivity Management
  - OIE 558 Designing and Managing Lean Six Sigma Processes

Degree Requirements

Interdisciplinary Master of Science in Bioscience Management

Admission

All applicants for this program must hold a bachelor's degree from an accredited college or university recognized by WPI. Acceptable bachelor's degrees include life science, management, engineering, and computer science. Students with other backgrounds may be considered with the approval of the program administrator. GRE and GMAT examinations are not required for admission to the program.

Requirements

Awarding of the degree requires successful completion of at least 30 credit hours of graduate coursework, not to exceed 14 credit hours in Biomedical engineering, within the Bioengineering or Custom Science tracks, and no more than 12 credit hours from any other discipline, including required or elective courses or directed research credits.

Curriculum

The Master of Science in Bioscience Management consists of three track options: Life Science, Bioengineering, and Custom Science. Although the courses are not specified in any of the tracks, the number of credit hours completed must conform to the breakdown found Table I.

Each student must have a Plan of Study approved by the program administrator within their first 9 credits.

Table I: Three track options for the Master of Science in Bioscience Management

Life Science Track:
6-12 Credit Hours in Chemistry/Biochemistry
6-12 Credit Hours in Management
6-12 Credit Hours in Biology/Biotechnology
3-9 Credit Hours of electives or directed research
Bioengineering Track:
9-14 Credit Hours in Biomedical Engineering
6-12 Credit Hours in Management
3-12 Credit Hours in Chemistry or Biology
3-9 Credit Hours of electives or directed research
Custom Science Track:
16-24 Credit Hours selected from Biomedical Engineering, Biology/Biotechnology, Chemistry/Biochemistry, Computer Science, Mathematical Science
6-12 Credit Hours in Management

Transfer Credits

Consistent with WPI policy in most graduate areas, up to one-third of the degree program (10 credit hours) may be transferred from an accredited college or university with approval of the program administrator.

Manufacturing Engineering Management

Faculty

Faculty hold a full time position in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

Program of Study

- Interdisciplinary Master of Science in Manufacturing Engineering Management

This program is designed to meet the demand from professionals who typically have an undergraduate degree in engineering, work experience in manufacturing, and a desire to pursue a master's degree curriculum with equal emphasis in both manufacturing engineering and manufacturing/operations management. They project their career as continuing to need a balanced growth in manufacturing engineering and manufacturing management.

Admissions Requirements

Students will be eligible for admission into the program if they have earned an undergraduate degree from an accredited university consistent with the WPI Graduate Catalog. Students should have a bachelor's degree in science or engineering. Students with other backgrounds will be considered based on their interest, formal education and experience in manufacturing. Admission decisions will be made by the sponsoring faculty based on all factors presented in the application, including prior academic performance, quality of professional experience, letters of recommendation, etc.

Degree Requirements

Interdisciplinary Master of Science in Manufacturing Engineering Management

Students must complete 30 credit hours of course work in Manufacturing, Engineering, and Management related courses as defined by the coordinating faculty.

Business (choose 12 credits)

- BUS 546 Managing Technological Innovation
- FP 563 Operations Risk Management
- MIS 500 Innovating with Information Systems
- MIS 576 Project Management
- OBC 505 Teaming and Organizing for Innovation
- OBC 537 Leading Change
- OIE 542 Risk Management and Decision Analysis
- OIE 544 Supply Chain Analysis and Design
- OIE 548 Productivity Management

Engineering (choose 15 credits)

- MFE 510 Control and Monitoring of Manufacturing Processes
- MFE 511 Application of Industrial Robotics
- MFE 520 / MTE 520 / ME 543 Design and Analysis of Manufacturing Processes
- MFE 530 / ME544 Computer-Integrated Manufacturing
- MFE 540 Design for Manufacturability
- MFE 598* Directed Research

Power Systems Management

Faculty

Faculty hold a full time position in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

Programs of Study

- Interdisciplinary Master of Science in Power Systems Management
- Certificate in Power Systems Management

Power Systems Engineering education is in high demand in the United States and more so in developing nations. WPI has broadened its offerings of courses in this area, and now offers a new level of flexibility for students and their current or prospective employers. In addition, the School of Business provides an attractive palette of relevant courses to enhance the professional skills of practicing engineers. This framework has created programs to meet industry demands.

Admissions Requirements

Students will be eligible for admission into the program if they have earned an undergraduate degree from an accredited university consistent with the WPI Graduate Catalog. Normally, an undergraduate bachelor's degree in electrical engineering, computer engineering, or computer science is expected. Students with other backgrounds may be considered with the approval of the faculty. GRE examinations are required for all international applicants.

Degree Requirements

Interdisciplinary Master of Science in Power Systems Management

At least 30 credit ours composed of:

- At least 12 credits but no more than 15 credits of graduate level coursework in Power Systems Engineering (course prefix ECE with course numbers from 5500 through 5599)
- At least 12 but no more than 14 credits of graduate level coursework in Business (example courses prefixed by BUS, MIS, OBC, OIE, etc.).

Electives:

Under the direction of the advisors, each student will select 6 credits of coursework at the 4000 level (maximum of two) or at the graduate level (designated as 500-, 5000-, or 600-level) in computer science (CS), physics (PH), engineering (BME, CHE, CE, ECE (1 only), FP, MFE, MTE, ME, RBE, and SYS), mathematics (MA), and/or Systems Dynamics (SD) to complete the Interdisciplinary Master of Science degree.

There is no thesis option for this degree.

Systems Engineering Leadership

Program of Study

The program allows students to increase their knowledge and skills in systems engineering while simultaneously increasing their business acumen. This interdisciplinary program blends technical training with business disciplines to provide critical skills and knowledge for leaders in highly technical and complex fields. The prescribed coursework will also enhance the students' ability to predict and model the impact of change in complex systems. Graduates will possess the skills necessary to holistically view, design and maintain complex systems and projects, and make effective business decisions as leaders in their organizations.

Return to Table of Contents

Admissions Requirements

The M.S. in Systems Engineering Leadership aims to attract candidates from a range of educational backgrounds that includes science, engineering, various business disciplines, and more. This flexible program was designed to attract candidates who possess a technical background and are looking to build their leadership skills, as well as those who may not have an engineering background and are seeking technical knowledge to continue their career growth within their organizations. The following will be required to be considered for admission:

- Official transcripts for all post-secondary colleges or universities showing that a bachelor's degree has been earned from a regionally accredited institution.
- Three letters of professional recommendation from individuals who can comment on student qualifications for pursuing graduate study.
- Statement of purpose
- Résumé
- GMAT or GRE scores—may be waived for candidates who hold a bachelor's degree from a regionally accredited institution with a minimum 3.0 GPA, with a course of study that included at least two quantitative courses with a grade of 3.0 or higher AND who meet one or more of the following three requirements:
  - Three or more years of professional work experience
  - A professional certification such as INCOSE SEP, PMI PMP, CPA, CFA, CFP, or Six Sigma.
  - An existing master's or earned doctorate with a GPA of 3.0 or higher

Degree Requirements

Interdisciplinary Master of Science in Systems Engineering Leadership

This interdisciplinary program requires 30 graduate credit hours of graduate-level work, distributed as follows:

12 Credits in Business Courses (Choose one from each category)

3 Credits in Leadership/Organizational Behavior and Change from the following list*:

- OBC 505 Teaming and Organizing for Innovation (3 Credits)
- OBC 506 The Heart of Leadership: Power, Reflection, and Interpersonal Skills (3 Credits)
- OBC 533 Negotiations (3 Credits)
- OBC 537 Leading Change (3 Credits)

3 Credits in Finance and Accounting from the following list*:

- ACC 500 Accounting and Finance Fundamentals (1 Credit)
- ACC 502 Financial Intelligence and Strategic Decision-Making (2 Credits)
- FIN 503 Financial Decision-Making for Value Creation (3 Credits)
- FIN 504 Financial Statement Analysis and Valuation (2 Credits)
- ACC 505 Performance Measurement and Management (1 Credit)

3 Credits in Marketing, Strategy, or Entrepreneurship from the following list*:

- BUS 546. Managing Technological Innovation (3 Credits)
- ETR 500. Entrepreneurship and Innovation(3 Credits)
- ETR 593. Technology Commercialization: Theory, Strategy and Practice (3 Credits)
- MKT 500 Marketing Management (3 Credits)
- MKT 568 Data Mining Business Applications (3 Credits)

3 Credits in Information Technology from the following list*:

- MIS 500 Innovating with Information Systems (3 Credits)
- MIS 571. Database Applications Development (3 Credits)
- MIS 573. System Design and Development (3 Credits)
- MIS 584. Business Intelligence (3 Credits)

*or other course(s) in the area with prior Program Review Board approval

12 Credits in Systems Engineering Courses

- SYS 501. Concepts of Systems Engineering (3 Credits)
- SYS 502. Business Practices (3 Credits)
- SYS 540. Introduction to Systems Thinking (3 Credits)
- SD 550. System Dynamics Foundation: Managing Complexity (3 Credits)

3 Credits in Technical Electives

- Any other graduate-level SYS course with Program Review Board approval (3 Credits)

3 Credit Required Capstone Project

- IDG 598 Systems Engineering Leadership Project

Course

IDG 598. Systems Engineering Leadership Project

This project-based course is an interdisciplinary exercise that integrates the technical aspects of systems engineering with the challenges of meeting business goals within the framework of the organizational structure. It allows students to apply the skills and knowledge acquired throughout the Systems Engineering Leadership curriculum. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. Each project is normally conducted in teams of two to four students. They are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced systems engineers. (Prerequisites: Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that the student will have completed most or all of the coursework within their plan of study before undertaking the engineering leadership project.)

Certificates

Certificate in Power Systems Management

This certificate program is proposed to meet the needs of a variety of corporations and individuals who are taking a first step toward an M.S. in Power Systems Management. The framework presents minimum requirements for the distribution of power systems and management courses, but provides flexibility for the student.

This certificate must consist of at least 17 credits of graduate coursework.

For more information please consult the WPI web at https://www.wpi.edu/academics/departments/power-systems

Course

IDG 599. Capstone Project Experience in Power Systems Management

This project-based course is an interdisciplinary exercise that integrates the technical aspects of power systems engineering with challenges of meeting business goals within the framework of the corporate organizational structure. It allows the students to apply the skills and knowledge acquired throughout the Power Systems Management curriculum. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. Each project is normally conducted in teams of two to four students. They are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Power Systems profession. (Prerequisites: Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that the student will have completed most or all of the coursework within their plan of study before undertaking the capstone project.)

Other Certificates

Certificate in Nuclear Science and Engineering

Faculty

The faculty hold a full time position in a WPI academic department or are adjunct faculty approved by an academic department and the NSE program review committee.

Program of Study and Certificate Requirements

The graduate certificate in nuclear science and engineering will require the successful completion of 12 graduate credits with an overall GPA of 3.00. The courses will be selected from the list below.

All students must successfully complete four of the five courses listed below:

- NSE 510 Introduction to Nuclear Science and Engineering (3 credits)
- NSE 520 Applied Nuclear Physics (3 credits)
- NSE 530 Health Physics (3 credits)
- NSE 540 Nuclear Materials (3 credits)
- NSE 550 Reactor Design and Operations (3 credits)

Admissions Requirements

Admission to the Nuclear Science and Engineering graduate certificate program is consistent with the admissions requirements listed in this catalog for graduate certificates. Appropriate undergraduate degree majors include all engineering and science majors.

Course Descriptions

NSE510. Introduction to Nuclear Science and Engineering

(3 credits) (offered annually)

This introductory course provides an overview of the field of nuclear science and engineering as it relates to nuclear power and nuclear technologies. Fundamental concepts relevant to nuclear systems are introduced, including radioactivity, radiation interaction phenomena, chain reaction physics, and transport in engineering materials. Nuclear reactor physics and design concepts are introduced with focus on light water fission reactors. A survey of advanced nuclear technologies and applications is provided. Prerequisites: graduate or senior standing or consent of the instructor.

NSE 520. Applied Nuclear Physics

(3 credits) (offered annually)

This course introduces engineering and science students to the fundamental topics of nuclear physics for applications, basic properties of the nucleus, nuclear radiations, and radiation interactions with matter. The course is divided into four main sections: (1) introduction to elementary quantum mechanics, (2) nuclear and atomic structure, (3) nuclear decays and radiation, and (4) nuclear matter interactions and nuclear reactions. Prerequisites: Physics of mechanics and electrodynamics (PH 1110/11 and PH 1120/21) and mathematical techniques up to and including ordinary differential equations (MA 2051)

NSE 530. Health Physics

(3 credit) (offered biennially)

This course builds on fundamental concepts introduced in NSE 510 and applies them to key topics in health physics and radiation protection. Health physics topics include man-made and natural sources of radiation, dose, radiation biology, radiation measurement, and radiation safeguards. Radiation protection concepts are explored as they apply to existing and advanced nuclear power generators, including reactor safety, nuclear waste and byproducts, regulatory constraints, and accident case studies. Prerequisites: graduate standing or consent of the instructor

NSE 540. Nuclear Materials

(3 credits) (offered biennially)

This course applies fundamental materials science concepts to effects on materials in harsh nuclear environments. An overview is provided on environments, special nuclear materials, and constraints in materials selection. Relationships are developed between nuclear effects on crystal structure, microstructure, degraded material performance, and bulk properties of engineering and electronic materials. Case studies provide examples of enhancements induced my multiple harsh environments and mitigation through material design hardening. Prerequisites: ES 2001 or equivalent.

NSE 550. Reactor Design, Operations, and Safety

(3 credits) (offered biennially)

This course provides a systems engineering view of commercial nuclear power plant technology. Power plant designs and their evolutions are studied, ranging from early to modern generation light water reactors, as well as advanced designs families, such alternate moderator and breeder reactors. Critical aspects of conventional power reactor designs are explored in detail, including steam supply, reactor core, control, and protection systems. Plant operational characteristics are studied, including reactor dynamics, control, feedback, and fuel cycle management. Critical power plant safety aspects of the design and operations are explored and reinforced with lessons learned from major power generator accidents scenarios (including Three Mile Island, Chernobyl, and Fukushima Daiichi). Prerequisites: graduate standing or consent of the instructor

NSE 595. Special Topics

(1-3 credits)

Arranged by faculty affiliate to the Nuclear Science and Engineering program for individual or groups of students, these courses survey areas that are not covered by the regular NSE course offerings. Exact course descriptions are disseminated by the NSE Program Committee well in advance of the offering. (Prerequisite: Consent of instructor.)

Learning Sciences and Technologies

Faculty

Learning Sciences & Technologies Core Faculty

N. T. Heffernan, Professor and Director; Ph.D., Carnegie Mellon University; Intelligent tutoring agents, artificial intelligence, cognitive modeling, machine learning

I. Arroyo, Associate Professor; Ed.D., M.S., University of Massachusetts, Amherst; learning with novel technologies; multimedia learning; intelligent tutoring systems; wearable learning and e-Textiles; learner characteristics and their relationship to learning; connection between affect and learning; educational data mining and student modeling.

R. Baker, Assistant Professor; Ph.D., Carnegie Mellon University; educational data mining, learner-computer interaction, gaming the system, student modeling, intelligent tutoring systems, educational games.

J. E. Beck, Assistant Professor; Ph.D., University of Massachusetts, Amherst; educational data mining, student modeling, Bayesian Networks, student individual differences

S. Djamasbi, Professor; Ph.D., University of Hawaii at Manoa; Usability, decision science.

L. Harrison, Assistant Professor; Ph.D., University of North Carolina at Charlotte; Information visualization, visual analytics, human-computer interaction.

E. Ottmar, Assistant Professor; Ph. D., University of Virginia; mathematics teaching and learning; mathematics development and cognition; interventions in schools; instructional quality; social and emotional learning; motivation and engagement; perceptual leaning; teacher/child interactions; observational measurement development

G. B. Somasse, Assistant Teaching Professor; Ph.D., Clark University; Development economics, applied econometrics, policy evaluation, public policy.

J. R. Whitehill, Assistant Professor; Ph.D., University of California, San Diego; Machine learning, crowdsourcing, automated teaching, human behavior recognition.

J. Zou, Associate Professor; Ph.D., University of Connecticut; Financial time series (especially high frequency financial data), spatial statistics, biosurveillance, high dimensional statistical inference, Bayesian statistics.

Learning Sciences & Technologies Associated Faculty

D. C. Brown, Professor; Ph.D., Ohio State University; Knowledge-based design systems, artificial intelligence

J. K. Doyle, Associate Professor; Ph.D., University of Colorado/Boulder; judgement and decision making, mental models of dynamic systems, evaluation of interventions

K. Fisler, Associate Professor; Ph.D., Indiana University; Interplay of human reasoning and formal logic in the context of hardware and software systems; current projects explore access-control policies and diagrams.

G. T. Heineman, Associate Professor; Ph.D., Columbia University; Component-based software engineering, formal approaches to compositional design

A. C. Heinricher, Professor; Ph.D., Carnegie Mellon University; applied probability, stochastic processes and optimal control theory

C. Ruiz, Professor; Ph.D., University of Maryland; Data mining, knowledge discovery in databases, machine learning

J. L. Skorinko, Professor; Ph.D., University of Virginia; soc ial environmental cues, stigmas and stereotyping, perceptions of others

Program of Study

The Learning Sciences and Technologies (LS&T) program offers graduate studies toward the M.S. and Ph.D. degrees. Our state-of-the-art facilities, faculty and strong relationships with K-12 schools provide students with the resources to perform innovative scientific research at the highest level. The diverse learning environment that characterizes our program promotes easy exchange of ideas, access to all the necessary resources, and encourages creative solutions to pressing scientific questions. The LS&T program is based on three affiliated areas – Computer Science, Cognitive and Educational Psychology, and Statistics – and provides opportunities for advanced course work and research for highly qualified students.

Admissions Requirements

Applicants must apply directly to the LS&T program. In order to be capable of performing graduate level work, applicants should have background in at least one of the core disciplines of LS&T, namely, Cognitive/Educational Psychology, Computer Science, or Statistics. We will also consider applicants whose academic background is in Science or Math.

A student may apply to the Ph.D. program in LS&T after completing a bachelor's degree (*in which case a master's degree must first be completed*) or a master's degree in one of the affiliated areas (Computer Science, Cognitive or Educational Psychology or Statistics) or a closely related area. Applicants with other degrees are welcome to apply if they can demonstrate their readiness through other means, such as GRE Subject exams in an affiliated area, or through academic or professional experience. GRE scores are strongly recommended, but not required, for all applicants. Inquiries about the GRE should be made to Dr. Neil Heffernan, the Program Director.

Return to Table of Contents

Degree Requirements

For the M.S.

The student may choose between two options to obtain the M.S. degree: thesis or coursework. Students should carefully weigh the pros and cons of these alternatives in consultation with their LS&T faculty advisor prior to selecting an option. Completion of the M.S. degree requires 33 graduate credit hours. M.S. LS&T students who wish to become doctoral candidates in LS&T must first complete their M.S. degree in LS&T following the thesis option.

To satisfy the interdisciplinary nature of the LS&T program, each M.S. student must complete the following 15 graduate credit hours that form the core requirements.

- Computer Science Requirement
  [6 graduate credit hours]
  Two LS&T Computer Science courses
- Cognitive Psychology Requirement
  [6 graduate credit hours]
  Two LS&T Cognitive Psychology courses
- Statistics Requirement
  [3 graduate credit hours]
  One LS&T Statistics course; or
  CS 567. Empirical Methods for Human-Centered Computing

No single graduate course can be double counted to satisfy two of the above requirements.

M.S. in LS&T – Coursework Option

In addition to the 15 graduate credit hours as required by the M.S. core requirements, a student pursuing the coursework option must register for an additional six graduate courses (totaling 18 graduate credit hours). To ensure a sufficient focus on LS&T, two of these courses (for a total of 6 graduate credit hours) must be from the LS&T course list. The remaining four courses (for a total of 12 graduate credit hours) are electives that relate to the student's individual program of study and must be selected in consultation with the student's LS&T advisor.

Note that M.S. graduate credits cannot be from independent study/research courses except by approval of the LS&T Program Director.

M.S. in LS&T – Thesis Option

In addition to the 15 graduate credit hours as required by the M.S. core requirements, a student pursuing the thesis option must satisfactorily complete a written thesis. Any Core or Associated LS&T faculty may serve as the thesis advisor. A thesis consisting of a research or development project worth a minimum of 9 graduate credit hours must be completed and presented to the LS&T faculty. A thesis proposal must be approved by the Core LS&T faculty and the student's advisor before the student can register for more than four thesis credits.

To complete the remaining 9 graduate credit hours, the student must register for an additional three graduate courses. To ensure a sufficient focus on LS&T, two of these courses (for a total of 6 graduate credit hours) must be from the LS&T course list. The remaining course (of 3 graduate credit hours) is an elective that relates to the student's individual program of study and must be selected in consultation with the student's LS&T advisor. As for the coursework option, M.S. graduate credits cannot be from independent study/research courses except by approval of the LS&T Program Director.

No Combined B.S./M.S. Degree

The LS&T program does not offer a combined B.S./M.S. degree.

For the Ph.D.

Students are advised to contact the program director for detailed program guidelines, in addition to the university's requirements for the Ph.D. degree. Students who wish to pursue a Ph.D. in LS&T who completed their M.S. at WPI in LS&T, must have chosen the thesis option.

Fundamentally, it is expected that all LS&T Ph.D. students master the basics of Learning Sciences, apply those concepts to create an innovative technology, and properly analyze their work with the appropriate statistical techniques. Ph.D. students will receive training through a combination of enrolling in courses, satisfying competency requirements and completing a dissertation; all Ph.D. students will be reviewed by the Core LS&T faculty at least once a year to see that they are making satisfactory progress towards these three components of the Ph.D. program.

Course Requirements

The Ph.D. degree in LS&T requires an additional 60 graduate credit hours of work beyond the M.S. degree. Students must take a minimum of 30 graduate credit hours of course work, including independent study, and 30 graduate credit hours of research.

To satisfy the interdisciplinary nature of the LS&T program, each Ph.D. student must complete the following 24 graduate credit hours. To count towards the course requirements, students must get a minimum grade of B for each of the courses. Students receiving a C or below must retake a course in the appropriate area and receive a B or higher.

- Computer Science Requirement
  [9 graduate credit hours]
  Three LS&T Computer Science courses
- Cognitive Psychology Requirement
  [9 graduate credit hours]
  Three LS&T Cognitive Psychology courses
- Statistics Requirement
  [6 graduate credit hours]
  LS&T Statistics courses, or
  CS 567. Empirical Methods for Human-Centered Computing

All students are required to submit a program of study that describes their planned course work; their LS&T advisor must approve the program. These classes can include graduate classes at WPI, classes at Clark University, particularly from their Psychology Department, and from independent studies. However, to ensure depth in LS&T, no more than 9 credit hours can be from disciplines other than Cognitive Psychology, Computer Science, and Statistics except by the approval of the Program Director.

Students can count previously taken LS&T courses towards these requirements. However, students must still complete 30 graduate credit hours of coursework for the Ph.D. degree. For example, if a student had taken two LS&T Computer Science courses as part of an LS&T M.S. degree, only one more LS&T Computer Science course would be required, but the student would still have to complete 30 graduate credit hours of coursework for the Ph.D. Similarly, students who are transferring in with an M.S. degree will be evaluated for which requirements they have fulfilled, but will still be required to take 30 graduate credit hours of coursework.

Return to Table of Contents

To complete the remaining 6 graduate credit hours, the Ph.D. student can register for other graduate courses or independent studies with approval of the student's LS&T advisor.

Competency Requirements

In addition to successful completion of their coursework, Ph.D. students must demonstrate competency in two core areas: Data Analysis and Communication (specifically, Speaking and Writing). Regarding Data Analysis, it is expected that students will learn analysis methods relevant to the Learning Sciences. We have selected these two areas as they are fundamental to success as an empirical scientist and will form the basis of LS&T graduates' future careers.

Competency in both Data Analysis and Communication will be assessed as follows: Students will be expected to conduct a pilot research study towards their graduate research. Students will submit a short paper (10-20 pages) to the Core LS&T faculty who will write a set of questions to be asked during a public presentation by the graduate student of the pilot research project. Possible venues for this include the AIRG (Artificial Intelligence Research Group) or the Learning Sciences Seminar. Students will be graded by at least two Core LS&T faculty on their responses to the LS&T questions, their data analysis, and communication skills at handling spontaneous questions during the talk. This requirement will be handled by the Core LS&T faculty.

Students must complete this competency requirement prior to defending their Ph.D. proposal. Furthermore, competency requirements must be completed within four semesters after students begin as Ph.D. students, except by permission of the Program Director.

Dissertation Requirements

Within six semesters of being admitted to the LS&T Ph.D. program, each student must form a dissertation committee, and write and defend a dissertation proposal. Any deviation from the timetable for the dissertation must be approved by the Program Director. Any Core or Associated LS&T faculty may serve as a research advisor.

A student's dissertation committee is composed of at least four members, as approved by the LS&T Core faculty. The committee must contain at least one Core LS&T faculty member and one faculty member external to WPI. To reinforce the interdisciplinary nature of the degree, at least two of the three cooperating departments (Computer Science, Social Science and Policy Studies and Mathematical Sciences) must have a faculty member on the dissertation committee. The dissertation committee will be responsible for approving the dissertation proposal and final report.

Students must enroll in at least 30 credits for their dissertation. Before presenting and defending their dissertation proposal, students may only enroll in 15 graduate research credit hours. Students are expected to defend their dissertation within six semesters of the acceptance of their dissertation proposal. In addition to the minimum of 30 graduate credit hours of research, the dissertation culminates in the student submitting the document itself and a public defense of the research.

Courses

LS&T Computer Science Courses

- CS 509 Design of Software Systems
- CS 534 Artificial Intelligence
- CS 538 Knowledge Based Systems
- CS 539 Machine Learning
- CS 540 Artificial Intelligence in Design
- CS 546 Human-Computer Interaction
- CS 548 Knowledge Discovery and Data Mining
- CS 565 User Modeling
- CS 566 Graphical Models for Reasoning Under Uncertainty
- CS 567 Empirical Methods for Human-Centered Computing
- CS 568 Artificial Intelligence for Adaptive Educational Technology

LS&T Cognitive Psychology Courses

- PSY 501 Foundations of the Learning Sciences
- PSY 502 Learning Environments in Education
- PSY 503 Research Methods for the Learning Sciences
- PSY 504 Meta-cognition, Motivation, and Affect
- PSY 505 Advanced Methods and Analysis for the Learning and Social Sciences

LS&T Statistics Courses

- MA 511 Applied Statistics for Engineers and Scientists
- MA 540/4631 Probability and Mathematical Statistics I
- MA 541/4632 Probability and Mathematical Statistics II
- MA 542 Regression Analysis
- MA 546 Design and Analysis of Experiments
- MA 547 Design and Analysis of Observational and Sampling Studies
- MA 554 Applied Multivariate Analysis
- MA 556 Applied Bayesian Statistics

Research Labs/Research Groups

Advanced Learning Technologies Research Lab

Prof. Arroyo

We create, explore, and analyze the impact of Learning Technologies for STEM focusing on a variety of important aspects of human learning. Our research spans many areas, including: Personalized Learning, Affect and Motivation, Metacognition, Embodied Cognition and Wearable Devices for Active Learning, Educational Games, Intelligent Pedagogical Agents, Students with Learning Disabilities, Cultural Differences in the design and implementation of Learning Technologies, and Learning Technologies for the Developing World.
http://alt.wpi.edu

Educational Data Mining Research Group

Profs. Beck, Heffernan, Whitehill & Arroyo

Large datasets of students' fine-grained interactions (e.g., student S answers math problem X with answer Y at time T) with intelligent tutoring systems, educational interventions, and massive open online courses (MOOCs) enable the exploration and optimization of how learners learn and how teachers teach. By harnessing methods from machine learning -- such as probabilistic graphical models, Markov chains, and deep neural networks -- we can develop more accurate predictors of which and when students will succeed, fail, persist, need help, etc. These predictors can, in turn, serve as the basis for both human-assisted and automated interventions to improve students' learning outcomes and the personalization of learning.

Educational Psychology and Mathematics Learning Lab

Prof. Ottmar

Teaching and learning mathematics is a highly complex social, exploratory, and creative process. We design novel dynamic technologies that make "math come alive" (Graspable Math, From Here to There!) and use eye tracking, mouse gestures, and log files to explore the coordination of attention, cognition, gestures, and strategies when solving mathematical equations. We also use a variety of applied multilevel quantitative methods, observational measures, and assessments to examine the efficacy of instructional, social, and emotional classroom Interventions that can improve K-12 math teaching, learning, and engagement. https://sites.google.com/site/erinottmar/

Embodied Cognition In Mathematics Research Group

Profs. Arroyo & Ottmar

This research group carries out research about new ways of learning, using motor actions as well as cognitive thought. We investigate how children may better learn mathematics while exploring the physical space, getting a different understanding of math learning by gesturing, and using technology to guide them through 3D spaces.

Machine Perception of Human Learning Group

Profs. Whitehill, Heffernan & Beck

This group uses machine learning and computer vision to study how learners learn and how they emote while they learn. Particular interests include the training of deep neural networks to recognize students' facial expressions during learning tasks, and the development of real-time cyberlearning systems that respond instantaneously to learners' current cognitive, affective, and linguistic needs.

Quantitative Methods in the Learning Sciences

Profs. Somasse, Ottmar, Zou & Heffernan

This research group is focus on rigorous quantitative methods such as hierarchical linear models (which is a typical method to use when students are nested inside teachers and teachers are nested inside schools). Other topics include issues that are used a lot in Learning Science like structural question modeling, longitudinal data analysis, propensity score matching, regression discontinuity designs, quasi-experimental designs and advanced topics like principal stratification. The faculty in this group like to apply (and adapt) statistical methodologies to solves the problems they are working on.

Running Classroom Experiments on the Web

Profs. Heffernan, Beck, Ottmar, Arroyo & Whitehill

We use a number of web-based platforms and technologies (i.e. ASSISTments, MathSpring, GraspableMath) to conduct randomized-controlled trials in K-12 mathematics classrooms. These studies help us understand "what works" with regards to different pedagogical techniques, content, feedback, and tasks, and helps us develop a better understanding of the mechanisms guiding learning. Together the group has over 100 randomized controlled trials running each year. There are a set of methodologic issues that their research group tackle related to student-level randomized controlled assignment.
http://www.neilheffernan.net/

Course Descriptions

All courses are 3 credits unless otherwise noted.

PSY/SEME 501. Foundations of the Learning Sciences

This course covers readings that represent the foundation of the learning sciences, including: Foundations (Constructivism, Cognitive Apprenticeship, & Situated Learning); Approaches (Project-based Learning, Model-based reasoning, Cognitive Tutors); and Scaling up educational interventions. The goal of this course is for students to develop an understanding of the foundations and approaches to the Learning Sciences so that they can both critically read current literature, as well as build on it in their own research. (Prerequisites: None)

PSY/SEME 502. Learning Environments in Education

In this class, students will read and review both classic and critical current journal articles about learning technologies developed in the Learning Sciences. This course is designed to educate students on current technological approaches to curricular design, implementation, and research in the Learning Sciences. (Prerequisites: None)

PSY/SEME 503. Research Methods for the Learning Sciences

This course covers research methods used in the Learning Sciences. Students will gain expertise and understanding of think-aloud studies, cognitive task analysis, quantitative and qualitative field observations, log file analysis, psychometric, cognitive, and machine-learning based modeling, the automated administration of measures by computer, and issues of validity, reliability, and statistical inference specific to these methods. Students will learn how and when to apply a variety of methods relevant to formative, performance, and summative assessment in both laboratory and field settings. Readings will be drawn primarily from original source materials (e.g. journal articles and academic book chapters), in combination with relevant textbook chapters. (Prerequisites: SS 2400, Methods, Modeling, and Analysis in Social Science, comparable course, or instructor discretion.)

PSY/SEME 504. Meta-cognition, Motivation, and Affect

This course covers three key types of constructs that significantly impact learning and performance in real-world settings, including but not limited to educational settings. Students will gain understanding of the main theoretical frameworks, and major empirical results, that relate individuals' meta-cognition, motivation, and affect to real-world outcomes, both in educational settings and other areas of life. Students will learn how theories and findings in these domains can be concretely used to improve instruction and performance, and complete final projects that require applying research in these areas to real-world problems. Students will do critical readings on research on this topic. (Prerequisites: None)

PSY 505. Advanced Methods and Analysis for the Learning and Social Sciences

This course covers advanced methods and analysis for the learning and social sciences, focusing on contemporary modeling and inference methods for the types of data generated in these forms of research. This course will enable students to choose, utilize, and make inferences from analytical metrics that are appropriate and/or characteristic to these domains, properly accounting for the characteristic forms of structure found in data typically collected for research in the learning and social sciences. Some of the topics covered will include ROC analysis and the use of A' for assessing student models, learning curve and learning factor analysis, social network and dyad analysis, and appropriate methods for tracking student learning and behavior in longitudinal data. Readings will be drawn from original source materials (e.g. journal articles and academic book chapters). (Prerequisites: PSY503, Research Methods for the Learning Sciences, comparable course, or instructor discretion.)

To see the Computer Science and Math classes, refer to those departments, pages 80 and 140.

Manufacturing Engineering

Faculty

B. Mishra, Kenneth G. Merriam Professor, Director, Materials & Manufacturing Engineering, Metal Processing Institute; Ph.D., University of Minnesota. Physico-chemical processing of materials; Corrosion science and engineering; Materials Processing, Surface Engineering, Resource Recovery & Recycling, Critical materials extraction; Iron and steelmaking; Alloy development; Thin film coatings.

C. A. Brown, Professor, Director, Surface Metrology Laboratory; Ph.D., University of Vermont. Surface metrology, multi-scale geometric analyses, axiomatic design, sports engineering, and manufacturing process.

M. S. Fofana, Associate Professor; Ph.D., University of Waterloo, Waterloo, Canada. Nonlinear delay dynamical systems, stochastic bifurcations, regenerative chatter, numerically controlled CAD/CAM machining.

C. Furlong, Professor; Ph.D., Worcester Polytechnic Institute. MEMS and MOEMS, nanotechnology, mechatronics, laser applications, holography, computer modeling of dynamic systems.

S. A. Johnson, Professor; Ph.D., Cornell University. Lean process design, enterprise engineering, process analysis and modeling, reverse logistics.

D. A. Lados, Milton Prince Higgins II Professor; Director, Integrative Materials Design Center (iMdc); Ph.D., Worcester Polytechnic Institute, 2004; Fatigue, fatigue crack growth, and fracture of metallic materials – life predictions, computational modeling and ICME, materials/process design and optimization for aerospace, automotive, marine, and military applications.

J. Liang, Professor; Ph.D., Brown University. Nanostructured materials, material processing, material characterization.

M. M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute. Solidification of Metals, the application of heat, mass and momentum transfer to modeling and solving engineering materials problems, and processing of ceramic materials.

S. Narra, Assistant Professor; Ph.D., Carnegie-Mellon University. Metal Additive Manufacturing; Powder bed fusion processes; Wire arc additive manufacturing; Process design; Process modeling; Machine learning for materials and mechanical engineering applications.

R. D. Sisson Jr., George F. Fuller Professor; Director, Manufacturing and Materials Engineering; Ph.D., Purdue University. Materials process modeling, manufacturing engineering, corrosion, and environmental effects on metals and ceramics.

D. Strong, Professor of Management and Department Head; Ph.D., Carnegie-Mellon University; Director, Management Information Systems (MIS) Program; MIS and work flows, data integration and role changes; MIS quality issues, data and information quality.

W. Towner, Associate Teaching Professor; Ph.D., Worcester Polytechnic Institute; operations management, lean manufacturing, six-sigma.

B. Tulu, Associate Professor of Management; Ph.D., Claremont Graduate University. Medical informatics, information security, telemedicine, personal health records, systems analysis and design.

Y. Wang, Professor of Mechanical Engineering; Ph.D., University of Windsor (Canada). Lithium ion battery, fuel cell, corrosion and electrochemistry, flow battery.

Faculty Research Interests

Current research areas include additive manufacturing, tolerance analysis, CAD/CAM, production systems analysis, machining, fixturing, delayed dynamical systems, nonlinear chatter, surface metrology, fractal analysis, surface functionality, metals processing and manufacturing management, axiomatic design, and abrasive processes, electronic medical records, lean in health care and health dynamics.

Programs of Study

The Manufacturing Engineering (MFE) Program offers two graduate degrees: the master of science and the doctor of philosophy. Full- and part-time study is available.

The graduate programs in manufacturing engineering provide opportunities for students to study current manufacturing techniques while allowing each student the flexibility to customize their educational program. Course material and research activities often draw from the traditional fields of computer science, controls engineering, electrical and computer engineering, environmental engineering, industrial engineering, materials science and engineering, mechanical engineering, and management. The program's intention is to build a solid and broad foundation in manufacturing theories and practices, and allow for further concentrated study in a selected specialty.

Admission Requirements

Candidates for admission must meet WPI's requirements and should have a bachelor's degree in science, engineering, or management, preferably in such fields as computer science/engineering, electrical/ control engineering, industrial engineering, environmental engineering, manufacturing engineering, materials science and engineering, mechanical engineering, or management. Students with other backgrounds will be considered based on their interest, formal education and experience in manufacturing.

Return to Table of Contents

Degree Requirements

For the M.S.

For the Master of Science in Manufacturing Engineering, the student is required to complete a minimum of 30 graduate credit hours. The course requirements are presented below. The student will choose between a thesis or Non-Thesis option.

Thesis Option

The student must complete a thesis with a minimum of six graduate credits. Additional thesis credits may substitute for elective courses. All elective courses must be approved by the student's advisor and the Director of Manufacturing Engineering or the Manufacturing Engineering Graduate Committee.

Non-Thesis Option

In addition to the course requirements in the four core areas a Capstone Project is required. This Capstone Project requirement can be met by successful completion of MFE 590 Capstone Project in Manufacturing Engineering or with a three credit Independent Study or Directed Research project in Manufacturing Engineering. All elective courses must be approved by the student's advisor and the Director of Manufacturing Engineering or the Manufacturing Engineering Graduate Committee.

Course Requirements

The Manufacturing Program is designed to focus on four core areas: the manufacturing process and design, materials processing, systems engineering and production/operations management. These topics are important to the design and control of the factories of the future. The MS in Manufacturing Engineering requires 30 graduate credits. The course requirements are presented below.

Manufacturing Process and Design: (4-6 graduate credits)

- MFE 510 Control and Monitoring of Manufacturing Processes (3)
- MFE 520 Axiomatic Design of Manufacturing Processes (3)
- MFE 531 Computer Integrated Manufacturing (2)
- MFE 541 Design for Manufacturability (2)

Materials Processing: (5-6 graduate credits)

- MTE 550 Phase Transformations (3)
- MTE 511 Structure and Properties of Engineering Materials (2)
- MTE 512 Properties and Performance of Engineering Materials (2)
- Any other MTE 5XXX course with the approval of the program director

Systems Engineering: (6 graduate credits)

- SYS 501 Concepts of Systems Engineering (3)
- SYS 502 Business Practices (3)
- SYS 540 Introduction to Systems Thinking (3)
- SD 550 Systems Dynamics Foundations: Managing Complexity (3)

Production/Operations Management: (6 graduate credits)

- OIE 501 Designing Operations for Competitive Advantage (3)
- OIE 544 Supply Chain Analysis and Design (3)
- OIE 548 Productivity management (3)
- OIE553 Global Purchasing and Logistics (3)
- OIE 555 Lean Process Design (3)
- OIE 558 Designing and Managing Lean Six Sigma Processes (3)

Capstone Project: (3 graduate credits)

- MFE 590 Capstone Project in Manufacturing Engineering (3)

Electives: (3-6 graduate credits)

- Select from any graduate science or engineering course, with approval of the program director.

For the Ph.D.

The doctoral (Ph.D.) program in MFE is a research degree requiring the following:

All candidates must pass a comprehensive written and oral exam. The written exam may be waived upon the recommendation of the advisor and approval of the MFE program director. All candidates must complete at least one year in residence, present and have a dissertation proposal accepted, the dissertation must be successfully presented and defended.

The dissertation is based on original research. A broad range of research topics is possible, including investigation into the fundamental science on which manufacturing processes are based, material science, manufacturing engineering education, metrology, quality, machine tool dynamics, manufacturing processes, design methodology and production systems, and health systems research.

All WPI requirements for a Ph.D. degree must be met.

MFE Seminar

Seminar speakers include WPI faculty and students as well as manufacturing experts and scholars from around the world. Registration for, attendance at and participation in the seminar course, MFE 500, is required for full-time students. The seminar series provides a common forum for all students to discuss current issues in manufacturing engineering.

Research Facilities and Laboratories

The CAM Laboratory

The CAM Lab facilitates the use of digital technologies to model, analyze, and control the manufacturing processes and systems. Besides the computers available for students, several application software packages have been used for CAD, solid modeling, kinematic analysis, FEA, modeling and simulation of machining and other materials processing, as well as new additive manufacturing processes. The lab has been developing techniques and systems for process (machining and heat treatment) modeling and simulation, production planning, tolerance analysis, fixture design, and lean manufacturing.

Manufacturing Interpreting Robotics Analysis Delay Dynamical Systems Laboratory (MIRAD)

The MIRAD laboratory focuses on developing computation, technology and engineering to better improve emergency medical services, ambulance vehicles, dialysis treatment, medical and public health systems, aircraft breaking systems, systems engineering mechanics and automated manufacturing systems design. Our innovative computerized modelling techniques, simulations, experiments and computer-controlled data acquisition to understand vibrations and

Return to Table of Contents

quantify uncertainty enable us to estimate optimal performance reliance of products, processes and systems in sustained ways. The partners of MIRAD Laboratory include but not limited to industry, academia, hospitals, EMS departments, research institutions and universities.

Manufacturing Laboratories

The manufacturing laboratories are spread out in six main areas in two buildings and house WPI's Haas Technical Education Center as well as WPI's Robotics Resource Laboratory, WPI's Collablab, and several student work spaces. In the Higgins Laboratories the facilities are located in rooms 004, 005, and 006. In the Washburn Shops the facilities are located in rooms 105, 107, and 108. The facilities are operated by an operations manager, and two lab machinists who are assisted by up to 20 undergraduate peer learning assistants (PLAs). Over 1000 WPI students use the facilities each year completing hundreds of individual and group projects. In a typical 7 week term we record over 4000 instances of use in the facilities which are available for student use 24 hours per day 365 days per year.

The Haas Technical Education Center was established with a $400,000 award from the Fleet Asset Management, trustee of the Elizabeth A. Lufkin Trust and Haas Automation, Oxnard, California, and represented in New England by Trident Machine tools, who entrusted WPI with over a quarter million dollars in new machine tools, software and training.

The center is used for both undergraduate teaching and graduate research. The eleven CNC machine tools are used in ME 1800, ME 3820, and ES 3323, as well as other courses. The machine tools facilitate the realization, i.e. fabrication, of parts that students have designed on computers. The machine tools are important for supporting WPI's project based-education. The machine tools are also be used in manufacturing engineering research, as well as to produce apparatus to support research efforts in other fields.

Higgins Machine Shop and Project Laboratory

The machine shop in the Higgins Labs consists of three adjacent areas: the Machine Shop (HL004, 600 sq. ft.), the Project Laboratory (HL005, 1600 sq. ft.), and the SAE Project Lab (HL006, 300 sq. ft.). The Machine Shop contains 2 CNC Machine tools (a Haas Tool Room min and a Haas Tool Room Lathe), as well as a surface grinder, 2 DoAll Mills and a DoAll engine lathe as well as a drill press, 2 band saws and assorted hand tools A machinist manages and supports the machine shop and project activities with the assistance of undergraduate PLAs. The Project Laboratory is used primarily for the conduct of capstone design projects requiring a large work and assembly area, such as the SAE Formula Race Car and other SAE projects. Typically, 12 –15 students are involved with the projects in this laboratory throughout the academic year.

In addition to providing space for capstone design projects the project lab also provides space to one of WPI's US First Robotics teams and supports the Robotics Resource Center, as well as being the home of WPI's CollabLab. The CollabLab is a student organization that promotes "maker" culture and collaboration at WPI.

Robotics Laboratory

The Robotics Laboratory, a 1,915 sq. ft. facility, is located on the first floor of the Washburn Building room 108 is equipped with a variety of industrial robots, machine tools and other equipment. The industrial robots, for which the Robotics Laboratory is named, are run primarily during the laboratory sessions of the Industrial Robotics course (ME 4815), and to a lesser extent by undergraduate project groups and graduate researchers. The industrial robots in the laboratory include: one Fanuc LR Mate 200iB, and one Fanuc M-710iC. The Robotics lab houses four of the five entrusted machine tools that are part of WPI's Haas Technical Education Center. The Mill Drill Center (MDC) is a permanent entrustment and has duel pallets so a part can be loaded while the machine is cutting. This machine is frequently used in conjunction with the Fanuc LR Mate. The Haas ST30-Y fully automated 4 axis machining center with an automatic bar feeder. Used in conjunction with the Fanuc ----- and the MDC students can create a fully automated production cell. Both the Haas VM2 and VF4-SS also located in the Robotics Lab are equipped with full 5 axis control systems. We have a Haas fifth axis fixturing system that can be mounted in either machine tool.

CNC Teaching Laboratory

The CNC teaching laboratory is located in the Washburn Shops Room 107 and covers 3,140 sq. ft. The mission of the CNC labs is to support the mission of WPI, by creating, discovering, and conveying knowledge at the frontiers of inquiry in CNC machining and education, as well as linking that new knowledge to applications; help students achieve self-sufficiency in the use of CNC tools and technologies, so they can conceive, design, and create their own CNC machined parts for their projects.

The vision of the CNC labs is to be the premier laboratory for CNC engineering education and research (applied and fundamental) in the world.

In the teaching laboratory we have one Universal Laser Systems VLS60 Laser Cutter, one Makerbot Replicator 2X, 3 Haas MiniMills and 2 Haas SL10s, 3 band saws, two drill presses, a sheet metal shear and bending break as well as assorted hand tools. Attached to each of the MiniMills and SL10s are computer workstations equipped with all of the design and programming software supported on campus and with our instructional tools that have been developed to allow students to train each other.

In addition to the computers located at each of the CNC machine tools in the CNC teaching laboratory and robotics laboratories the facility has two computer classroom spaces one located in 107 with the other in 105. Each of the classroom spaces can be configured to contain between 8 and 12 computer workstations. Each space also has, a conference table, whiteboards, and a ceiling mounted projector that each computer in the space can send its signal to when the spaces are used for project group meetings.

Students working on any of the computer workstations in the facilities have access to the design software packages supported on campus as well as our training materials and several Computer Aided Manufacturing (CAM) software packages including Esprit, MasterCam, and SurfCam.

Metal Processing Institute (MPI)

The Metal Processing Institute (MPI) is an industry-university alliance. Its mission is to design and carry out research projects identified in collaboration with MPI's industrial partners in the field of near and net shape manufacturing. MPI develops knowledge that will help enhance the productivity and competitiveness of the metal processing industry and develops the industry's human resource base through the education of WPI students. Over 90 corporate partners participate in the Institute, and their support helps fund fundamental and applied research that addresses technological barriers facing the industry. MPI is one of WPI's two Institutes with a legacy based on Theory and Practice. MPI houses three centers: the Advanced Casting Research Center (ACRC); the Center for Heat Treating Excellence (CHTE); and the Center for Resource Recovery and Recycling (CR3). The latter is a multi-university center with CSM and KU Leuven.

Surface Metrology Laboratory

WPI's Surface Metrology Lab is one of just a few academic labs in the world that focuses on measurement and analysis of surface topographies, or roughness. Through the generosity of the respective companies the lab has the use of an Olympus LEXT OLS4100 laser scanning confocal microscope, a Solarius SolarScan white light microscope and a Mahr-Federal MarSurf GD25 stylus profiler for measuring topographies, as well as Mountains Map (DigitalSurf), Modal Filter, and Sfrax, software for analysis. We study how topographies are influenced by processing and influence the performance of surfaces. One task it to find ways to discriminate surfaces that were processed differently, or that perform differently, based on topographic measurement and analysis. Another task is to find functional correlations between topographies and their processing or their performance. The lab has pioneered the development and application of several kinds of multi-scale analyses including geometric and fractal analyses for discrimination and correlation. The lab serves industry and collaborates with engineers and scientists from a variety of disciplines around the world.

Course Descriptions

All courses are 3 credits unless otherwise noted.

MFE 500. Current Topics in Manufacturing Seminar

(0 credits)

This seminar identifies the typical problems involved in a variety of manufacturing operations, and generic approaches for applying advanced technologies to implement operations. Topical areas of application and development such as intelligent materials processing, automated assembly, MRP and JIT scheduling, vision recognition systems, high-speed computer networks, distributed computer control of manufacturing processes and flexible manufacturing systems may be covered. This seminar is coordinated with the undergraduate program in manufacturing engineering. *Required for all full-time students.*

MFE 510. Control and Monitoring of Manufacturing Processes

(3 Credits)

Covers a broad range of topics centered on control and monitoring functions for manufacturing, including process control, feedback systems, data collection and analysis, scheduling, machine-computer interfacing and distributed control. Typical applications are considered with lab work.

MFE 511. Application of Industrial Robotics

(2 Credits)

(Concurrent with ME 4815) This course introduces the student to the field of industrial automation. Topics covered include robot specification and selection, control and drive methods, part presentation, economic justification, safety, implementation, product design and programming languages. The course combines the use of lecture, project work and laboratories that utilize industrial robots. Theory and application of robotic systems will be emphasized.

MFE 520/MTE 520/ME 543. Axiomatic Design of Manufacturing Processes

(3 Credits)

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability.

This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

MFE/MTE 521. Fundamentals of Axiomatic Design of Manufacturing Processes

(2 credits)

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools.

Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543

MFE 531/ME 5431. Computer Integrated Manufacturing

(2 Credits)

An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. Emphasis is placed on CAD/CAM integration. Topics include, part design specification and manufacturing quality, tooling and fixture design, and manufacturing information systems. This course includes a group term project. (Prerequisites: Background in manufacturing and CAD/CAM, e.g., ME 1800, ES 1310, ME 3820.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE 593D/MFE 594D).

Return to Table of Contents

MFE 541/ME 5441. Design For Manufacturability

(2 Credits)

The problems of cost determination and evaluation of processing alternatives in the design-manufacturing interface are discussed. Approaches for introducing manufacturing capability knowledge into the product design process are covered. An emphasis is placed on part and process simplification, and analysis of alternative manufacturing methods based on such parameters as: anticipated volume, product life cycle, lead time, customer requirements, and quality yield. Lean manufacturing and Six-Sigma concepts and their influence on design quality are included as well. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE594M).

MFE/MTE 5841. Surface Metrology

(3 Credits)

This course emphasizes research applications of advanced surface metrology, including the measurement and analysis of surface roughness. Surface metrology can be important in a wide variety of situations including adhesion, friction, catalysis, heat transfer, mass transfer, scattering, biological growth, wear and wetting. These situations impact practically all the engineering disciplines and sciences. The course begins by considering basic principles and conventional analyses, and methods. Measurement and analysis methods are critically reviewed for utility. Students learn advanced methods for differentiating surface textures that are suspected of being different because of their performance or manufacture. Students will also learn methods for making correlations between surface textures and behavioral and manufacturing parameters. The results of applying these methods can be used to support the design and manufacture of surface textures, and to address issues in quality assurance. Examples of research from a broad range of applications are presented, including, food science, pavements, friction, adhesion, machining and grinding. Students do a major project of their choosing, which can involve either an in-depth literature review, or surface measurement and analysis. The facilities of WPI's Surface Metrology Laboratory are available for making measurements for selected projects. Software for advanced analysis methods is also available for use in the course. No previous knowledge of surface metrology is required. Students should have some background in engineering, math or science.

MFE 590. Capstone Project in Manufacturing Engineering

The new capstone course (MFE 590) will provide a practical experience for the students in the M.S. MFE Program to synthesize their learning and to apply knowledge to solving real-world manufacturing problems. The projects will be sponsored by either internal units on campus or external organizations. In addition to a written report, the project results will be formally presented to the class, outside sponsors and other interested parties.

MFE 594. Special Topics

Theoretical and experimental studies in subjects of interest to graduate students in manufacturing engineering. (Prerequisite: Consent of instructor.) The description of each Special Topics course is attached to the course number as seen on the course schedule posted on the Registrar's website.

MFE 598. Directed Research

MFE 599. Thesis Research

Materials Science and Engineering

www.wpi.edu/+MPE

Faculty

B. Mishra, Kenneth G. Merriam Professor, Director, Materials & Manufacturing Engineering, Metal Processing Institute; Ph.D., University of Minnesota. Physico-chemical processing of materials; Corrosion science and engineering; Materials Processing, Surface Engineering, Resource Recovery & Recycling, Critical materials extraction; Iron and steelmaking; Alloy development; Thin film coatings.

C. A. Brown, Professor; Director, Surface Metrology Lab; Ph.D., University of Vermont. Surface metrology, multi-scale geometric analyses, axiomatic design, sports engineering, and manufacturing processes.

D. Cote, Assistant Professor, Director, Center for Materials Processing Data (CMPD); Ph.D., Worcester Polytechnic Institute. Computational thermodynamics and kinetics; Phase transformations; Powder metallurgy.

C. Demetry, Professor; Director, Morgan Teaching and Learning Center, Ph.D., Massachusetts Institute of Technology. Materials science and engineering education, nanocrystalline materials and nanocomposites, ceramics, and grain boundaries and interfaces in materials.

D. A. Lados, Milton Prince Higgins II Professor; Director, Integrative Materials Design Center (iMdc); Ph.D.,Worcester Polytechnic Institute. Fatigue, fatigue crack growth, thermo-mechanical fatigue, creep, and fracture of metallic materials – life predictions, computational modeling and ICME, materials/process design and optimization for aerospace, automotive, marine, and military applica tions; advanced material characterization; additive manufacturing, metal matrix nano–composites, friction stir welding, cold spray technology, powder metallurgy; residual stress; plasticity; fracture mechanics.

Jianyu Liang, Professor, Ph.D., Brown University. Additive manufacturing, nanostructured materials, material processing, material characterization.

M. M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute. Solidification of Metals, the application of heat, mass and momentum transfer to modeling and solving engineering materials problems, and processing of ceramic materials.

S. Narra, Assistant Professor; Ph.D., Carnegie-Mellon University. Metal Additive Manufacturing; Powder bed fusion processes; Wire arc additive manufacturing; Process design; Process modeling; Machine learning for materials and mechanical engineering applications.

A. Powell, Associate Professor; Ph.D., Massachusetts Institute of Technology. Clean production of materials particularly those used in clean energy, electro chemistry, extractive metallurgy, multiscale modeling of materials process fundamentals, inductrial ecology.

P. Rao, Associate Professor; Ph.D., Stanford University. Solar energy materials, photovoltaic and photoelectrochemical materials, scalable synthesis of nanostructored thin film materials.

S. Shivkumar, Professor; Ph.D., Stevens Institute of Technology. Biomedical materials, plastics, materials processing.

R. D. Sisson Jr., George F. Fuller Professor; Ph.D., Purdue University. Materials process modeling and control, manufacturing engineering, corrosion, and environmental effects on metals and ceramics.

W. Soboyejo, Bernard M. Gordon Dean of Engineering, Professor of Engineering Leadership; Ph.D., Cambridge University. materials science, biomaterials, materials for energy systems and multifunctional materials for sustainable development.

L. Wang, Research Professor, Ph.D., Drexel University. Casting technology, aluminum casting alloy development and characterization, heat treatment, molten metal processing, and solidification processing.

Y. Wang, William Smith Foundation Dean's Professor; Ph.D., University of Windsor (Canada). Lithium ion battery, fuel cell, corrosion and electrochemistry, flow battery.

M. Yang, Assistant Research Professor, Associate Director of the Center for Heat Treating Excellence; Ph.D., Worcester Polytechnic Institute. Thermal Processing of Metals and Alloys, Integrated Computational Materials Engineering.

Y. Zhong, Associate Professor; Ph.D., Pennsylvania State University. Computational Thermodynamics, Integrated materials and processes design (IMPD), Next generation alloys and ceramics.

Program of Study

Materials Science and Engineering (MTE) offers programs leading to a degree of master of science and/or doctor of philosophy.

The master of science in materials science and engineering provides students with an opportunity to study the fundamentals of materials science and state-of-the-art applications in materials engineering and materials processing. The program is designed to build a strong foundation in materials science along with industrial applications in engineering, technology and processing. Both full- and part-time study are available.

Program areas for the doctor of philosophy emphasize the processing-structure-property-performance relationships in metals, ceramics, polymers and composites. Current projects are addressing these issues in fuel cell materials, biopolymers, aluminum and magnesium casting, the heat-treating of steels and aluminum alloys and metal matrix composites.

Well-equipped laboratories within Washburn Shops and Stoddard Laboratories include such facilities as scanning (SEM) and transmission (TEM) electron microscopes, X-ray diffractometer, process simulation equipment, a mechanical testing laboratory including two computer-controlled servohydraulic mechanical testing systems, metalcasting, particulate processing, semisolid processing laboratories, a surface metrology laboratory, a metallographic laboratory, a polymer engineering laboratory with

Return to Table of Contents

differential scanning calorimeter (DSC), a corrosion laboratory, topographic analysis laboratory and machining force dynamometry. A range of materials processing, fastening, joining, welding, machining, casting and heat treating facilities is also available.

Admission Requirements

The program is designed for college graduates with engineering, mathematics or science degrees. Some undergraduate courses may be required to improve the student's background in materials science and engineering. For further information, see page 9.

Degree Requirements

For the M.S.

For the master of science in materials science and engineering, the student is required to complete a minimum of 30 graduate credit hours. Requirements include MTE 511 and MTE 512 and at least 4 of the following courses: MTE 526, MTE 532, MTE 540, MTE 550, MTE 561. For the remaining credits, the student may choose between a thesis or coursework option and Directed Research.

Thesis Option

The student must complete a thesis with a minimum of 6 graduate credits. Additional thesis credits may substitute for course electives. The remaining graduate credits must consist of additional MTE or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. All courses must be approved by the student's advisor and the Materials Graduate Committee.

Non Thesis Option

The student must complete a three credit capstone project or equivalent that demonstrates the ability to design, implement, and complete an independent professional project. The remaining graduate credits must consist of additional MTE or other 4000-, 500- or 600-level engineering, science, management or mathematics electives. All courses must be approved by the student's advisor and the Materials Graduate Committee.

Satisfactory participation in the materials engineering seminar (MTE 580) is also required for all full-time students. In addition to general college requirements, all courses taken for graduate credit must result in a GPA of 3.0 or higher. Waiver of any of these requirements must be approved by the Materials Science and Engineering Graduate Committee, which will exercise its discretion in handling any extenuating circumstances or problems.

Examples of Typical Program

- Materials engineering core courses—18 credits
- Electives—6 credits
- Thesis—6 credits
- **Total—30 credits**

For the Ph.D.

The number of course credits required for the doctor of philosophy degree, above those for the master of science, is not specified precisely. For planning purposes, the student should consider a total of 21 to 30 course credits. The remainder of the work will be in research and independent study. The total combination of research and coursework required will not be less than 60 credits beyond the master of science degree or not less than 90 credits beyond the bachelor's degree.

Admission to candidacy will be granted only after the student has satisfactorily passed the Materials Engineering Doctoral Qualifying/ Comprehensive Examination (MEDQE). The purpose of this exam is to determine if the student's breadth and depth of understanding of the fundamental areas of materials engineering is adequate to conduct independent research and successfully complete a Ph.D. dissertation.

The MEDQE consists of both written and oral components. The written exam must be successfully completed before the oral exam can be taken. The oral exam is usually given within two months of the completion of the written exam. The MEDQE is offered at least one time each year.

A member of the materials science and engineering faculty will be appointed to be the chairperson of the MEDQE Committee. This person should not be the student's Ph.D. thesis advisor; but that advisor may be a member of the MEDQE Committee. Others on the committee should be the writers of the four sections of the examinations and any other faculty selected by the chairperson. Faculty from other departments at WPI or other colleges/universities, as well as experts from industry, may be asked to participate in this examination if the materials engineering faculty deems that it is appropriate.

At least one year prior to completion of the Ph.D. dissertation, the student must present a formal seminar to the public describing the proposed dissertation research project. This Ph.D. research proposal will be presented after admission to candidacy.

Materials Science and Engineering Laboratories and Research Centers

Electrochemical Energy Laboratory

The electrochemical energy laboratory is equipped for analyzing a variety of electrochemical reactions. Examples of these reactions include electrolysis of metal salts for primary metal production, lithium ion transport in lithium ion batteries and reactions involved in colloidal flow battery suspensions. The equipment includes three different electrochemical analyzers (Bio-logic electrochemical tester with 10 channels, Newware Battery testing system, Arbin BT2043 with MitsPro4.0 System), and a two-person MBRAUN Glovebox. Additionally several furnaces, oven, high energy ball mill, overhead stirrer, spin coater and a hydraulic press are available for electrode preparation. The lab also includes a Shutte Buffalo W-6-H hammermill for recycling related projects.

Integrative Materials Design Center (iMdc)

iMdc is a WPI-based research center dedicated to advancing the state-of-the-art-and-practice in sustainable materials-process-component design and manufacturing for high-performance, reliability, and recyclability through knowledge creation and dissemination, and through education.

iMdc is formed through an industry-government-university alliance, and its program is built in direct collaboration, and with active participation and insight from its industrial and government partners. The center is conducting fundamental research, which addresses well-identified industrial applications of general interest and relevance to the manufacturing sector.

The overarching objective of the iMdc's research portfolio is to prevent failure and increase high–performance and reliability of high-integrity structures through:

- Exploring and advancing the fundamental and practical understanding of a wide range of multi-scale metallic and composite materials and their respective processes
- Developing new and optimized materials and processing practices, including recycling as a design factor
- Establishing knowledge-based microstructure-properties-performance relationships
- Investigating the impact of increased utilization of recycled materials in high-performance materials and applications
- Providing practical and integrated design and computational (ICME) methods and tools
- Identifying and pursuing implementation venues for the developed materials, processes, and design methodologies

Industrial and government partners review and provide insight and guidance to the research programs, bring industrial perspective, and assist in identifying strategies for the implementation of the developments in the industry. This setting provides a platform for creating knowledge in a well-defined context while being able to disseminate it and witness its implementation and impact in/on actual industrial applications.

Materials Characterization Laboratory

The Materials Characterization Laboratory (MCL) is an analytical user facility, which serves the materials community at WPI, offering a range of analytical techniques and support services. Licensed users have 24/7 access to instruments including JEOL 7000F field-emission gun scanning electron microscope, JEOL 100CXII transmission electron microscope, PANalytical Empyrean x-ray diffractometer, Spectro MAXx LMX04 Spectrometer, Agilent Nanoindenter, Clark CM-400AT microhardness indenter, Shimazu HMV-2000 Microhardness tester, Buehler Microhardness tester, Rockwell hardness testers, and more than 10 grinding and polishing machines. The MCL is also open to researchers from other universities and local industries.

Metal Processing Institute (MPI)

The Metal Processing Institute (MPI) is an industry-university alliance dedicated to advancing available technology to the metal processing and materials recovery and recycling industries. Students, professors and more than 90 industry partners work together on research projects that address technological barriers facing industry – making member businesses more competitive and productive.

MPI offers educational opportunities and corporate resources to undergraduate and graduate students. They include:

- International exchanges and internships with several leading universities in Europe and Asia.
- Graduate internship programs leading to a master's or doctoral degree, where the research is carried out at the industrial site.

MPI's research programs are managed by three distinct research centers:

- Advanced Casting Research Center (ACRC) – more information below.
- Center for Heat Treating Excellence (CHTE) – more information below.
- Center for Resource Recovery and Recycling (CR3) – more information below.

For further information please visit the MPI offices on the third floor of Washburn, Room 326. Our visit our website: http://wpi.edu/+mpi

Center for Heat Treating Excellence (CHTE)

At the Center for Heat Treating Excellence (CHTE) students get to work with industry leaders and WPI faculty to solve business challenges and improve manufacturing processes through applied research.

Students will have the opportunity to work with over 20 corporate members from various parts of the heat treating industry – commercial heat treaters, captive heat treaters, suppliers and manufacturers.

Research projects focus on:

- Reducing energy consumption
- Controlling microstructure and properties of metallic components
- Reducing processing time
- Minimizing production costs
- Achieving zero distortion
- Increasing furnace efficiency

Project opportunities, industrial internships, co-op opportunities and summer employment are available through CHTE. http://wpi.edu/+chte

Center for Resource Recovery and Recycling (CR^3)

In nature, nothing is wasted. The Center for Resource Recovery & Recycling (CR^3) is the premiere industry-university collaborative that works towards taking the waste from one process and utilizing it in another, establishing a closed loop system – just as nature would. CR^3's mission is to be the ultimate resource in material sustainability.

Students who work with CR^3 will work with industry leaders on technological advancements that recover and recycle materials from initial product design, through manufacture to end-of-life disposition. The end result: enhanced environmental conservation, and im proved energy and cost savings.

Recent projects include:

- Near 100% auto recycling rates
- Dist recovery and recycling improvements
- Recovery of valuable materials from waste fluorescent
- Transformation of waste streams to value added materials

CR^3 is an Industry and University Center (I/UCRC) and is supported by the National Science Foundation (NSF). Partner universities include Colorado School of Mines and KU Leuven, Belgium. For more information: https://wpi.edu/+cr3

Mineral Processing Laboratory

The Mineral Processing Lab consists of state of the art facilities to carry out physical separation, hydro, and pyrometallurgical operations to separate and recover base metals and critical elements from waste streams and primary ores.

The lab consists of an attrition mill for primary size reduction and grinding of feed material. The mill runs in both dry and wet media at RPM of 100 to 500 with grinding media ranging from 1/8" to 2". Furthermore, to study the particle size distribution after grinding, the lab consists of a Sieve Shaker (RX-29) to classify particles ranging from 45 to 600 microns.

The Frantz Magnetic Barrier Laboratory Separator (LB-1) separates mineral components according to their paramagnetic and diamagnetic susceptibility. With optimized orientation of inclined chute and magnetic system, the desired relationship between gravitational and magnetic forces can be achieved for effective separation. The lab also consists of a custom-built wet drum magnetic separator (Steinert make). Rotating magnetic drums separate the magnetic particles from slurry and are further scraped off from the drum surface by separating splitter to obtain highly concentrated magnetic concentrate.

Heat treatment experiments are performed in a controlled atmosphere furnace (Carbolite Gero, HTMA 6/28) with a maximum temperature of 600 °C and 95 L volume, and 180 L laboratory oven (Fisherbrand) for heating of samples in 50 – 250 °C range.

The large-scale leaching setup consists of two 100 L stainless steel (SS316) tank along with an overhead electric motor with shaft for mixing of slurry. The filtration system consists of a settling tank, bag filter with a cut off size of 5 microns, and a pressure filter for filtration of particles above 1 micron and a stainless-steel hydro cyclone with 7 to 10-micron separation efficiency. Gamry Reference 600 is used to recover elements with the electro-winning approach and study electrochemical corrosion and check cyclic voltammetry.

NanoEnergy Laboratory

Research in the NanoEnergy Lab targets the synthesis and study of ordered nanomaterials for energy conversion applications, particularly for converting solar energy to electrical or chemical energy. The goal is to use nanostructuring and scalable, economical synthesis methods to dramatically improve the energy conversion efficiency of earth-abundant, low-cost materials.

Projects in the NanoEnergy Lab focus on:

- Flame-synthesis of complex, hierarchical, ordered nanomaterials
- Design, synthesis and characterization of nanostructured materials for solar energy conversion (photovoltaic and photoelectrochemical)

Nanomaterials synthesis equipment in the NanoEnergy lab includes vapor deposition (flat-flame burner and multi-zone tube furnace), hydrothermal synthesis reactors, solution deposition (fume hood, spin-coater), and various furnaces for annealing materials. Light sources, integrating spheres, spectrometers, a potentiostat, electrochemical cells and chemical sensors are available for the characterization of optical, electronic and electrochemical properties of materials.

The NanoEnergy Lab is located in Rooms 4916 and 4918, 50 Prescott St. (Gateway Park II). For further information, please see nanoenergy.wpi.edu.

Nanomaterials and Nanomanufacturing Laboratory

This laboratory is well-equipped for advanced research in controlled nano-fabrications and nanomanufacturing of carbon nanotubes, magnetized nanotubes, semiconducting, superconducting, magnetic, metallic arrays of nanowires and quantum dots. Nanomaterials fabrication and engineering will be carried out in this laboratory by different means, such as PVD (physical vapor deposition), CVD (chemical vapor deposition), PECVD (plasma enhanced CVD), RIE (reactive ion etching), ICP etching (induced coupled plasma), etc. Material property characterizations will be conducted, including optic, electronic, and magnetic property measurements. Nanostructured device design, implementation, and test will also be carried out in this lab.

Polymer Laboratory

This laboratory is used for the synthesis, processing and testing of plastics. The equipment includes: thermal analysis machines Perkin Elmer DSC 4, DSC 7, DTA 1400 and TGA 7; single-screw table-top extruder; injection molding facilities; polymer synthesis apparatus; oil bath furnaces; heat treating ovens; and foam processing and testing devices.

Surface Metrology Laboratory

WPI's Surface Metrology Lab is one of just a few academic labs in the world that focuses on measurement and analysis of surface topographies, or roughness. Through the generosity of the respective companies the lab has the use of an Olympus LEXT OLS4100 laser scanning confocal microscope, a Solarius SolarScan white light microscope and a Mahr-Federal MarSurf GD25 stylus profiler for measuring topographies, as well as Mountains Map (DigitalSurf), Modal Filter, and Sfrax, software for analysis. We study how topographies are influenced by processing and influence the performance of surfaces. One task it to find ways to discriminate surfaces that were processed differently, or that perform differently, based on topographic measurement and analysis. Another task is to find functional correlations between topographies and their processing or their performance. The lab has pioneered the development and application of several kinds of multi-scale analyses including geometric and fractal analyses for discrimination and correlation. The lab serves industry and collaborates with engineers and scientists from a variety of disciplines around the world.

Course Descriptions

All courses are 3 credits unless otherwise noted.

MTE 509. Electron Microscopy

(2 credits)

This course introduces students to the theory, fundamental operating principles, and specimen preparation techniques of scanning electron microscopy (SEM), transmission electron microscopy (TEM), and energy dispersive x-ray spectroscopy (EDS). The primary emphasis is placed on practical SEM, TEM, and x-ray microanalysis of materials. Topics to be covered include basic principles of the electron microscopy; SEM instrumentation, image formation and interpretation, qualitative and quantitative x-ray microanalysis in SEM; electron diffraction and diffraction contrast imaging in TEM. Various application examples of SEM and TEM in materials research will be discussed. Lab work will be included. The course is available to graduate students. Recommended background: CH 1020, PH 1120, and ES 2001 or equivalent. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

MTE 511/ME 5311. Structure and Properties of Engineering Materials

(2 credits)

This course, (along with its companion course MTE 512 Properties and Performance of Engineering Materials), is designed to provide a comprehensive review of the fundamental principles of Materials Science and Engineering for incoming graduate students. In the first part of this 2 course sequence, the structure in materials ranging from the sub-atomic to the macroscopic including nano, micro and macromolecular structures will be discussed to highlight bonding mechanisms, crystallinity and defect patterns. Representative thermodynamic and kinetic aspects such as diffusion, phase diagrams, nucleation and growth and TTT diagrams will be discussed. Major structural parameters that effect of performance in materials including plastics, metallic alloys, ceramics and glasses will be emphasized. The principal processing techniques to shape materials and the effects of processing on structure will be highlighted. (Prerequisites: senior or graduate standing or consent of the instructor.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594S).

MTE 512/ME 5312. Properties and Performance of Engineering Materials

(2 credits)

The two introductory classes on materials science (MTE 511 and MTE 512) describe the structure-property relationships in materials. The purpose of this class is to provide a basic knowledge of the principles pertaining to the physical, mechanical and chemical properties of materials. The primary focus of this class will be on mechanical properties. The thermal, tensile, compressive, flexural and shear properties of metallic alloys, ceramics and glasses and plastics will be discussed. Fundamental aspects of fracture mechanics and viscoelasticity will be presented. An overview of dynamic properties such as fatigue, impact and creep will be provided. The relationship between the structural parameters and the preceding mechanical properties will be described. Basic composite theories will be presented to describe fiber-reinforced composites and nanocomposites. Various factors associated with material degradation during use will be discussed. Some introductory definitions of electrical and optical properties will be outlined. (Prerequisites: MTE 511 and senior or graduate standing or consent of the instructor) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594P).

MTE 520/MFE 520/ME 543. Axiomatic Design of Manufacturing Processes

(3 credits)

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability.

This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE 521, MTE 521.

MTE/MFE 521. Fundamentals of Axiomatic Design of Manufacturing Processes

(2 credits)

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools.

Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

MTE 526. Advanced Thermodynamics

(2 credits)

Thermodynamics of solutions—phase equilibria— Ellingham diagrams, binary and ternary phase diagrams, reactions between gasses and condensed phases, reactions within condensed phases, thermodynamics of surfaces, defects and electrochemistry. Applications to materials processing and degradation will be presented and discussed. (Prerequisites: ES 3001, ES 2001) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594T).

MTE 532. X-Ray Diffraction and Crystallography

(2 credits)

This course discusses the fundamentals of crystallography and X-ray diffraction (XRD) of metals, ceramics and polymers. It introduces graduate students to the main issues and techniques of diffraction analysis as they relate to materials. The techniques for the experimental phase identification and determination of phase fraction via XRD will be reviewed. Topics covered include: basic X-ray physics, basic crystallography, fundamentals of XRD, XRD instrumentation and analysis techniques. (Prerequisites: ES 2001 or equivalent, and senior or graduate standing in engineering or science.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594C).

MTE 540. Analytical Methods in Materials Engineering

(3 credits)

Heat transfer and diffusion kinetics are applied to the solution of materials engineering problems. Mathematical and numerical methods for the solutions to Fourier's and Pick's laws for a variety of boundary conditions will be presented and discussed. The primary emphasis is given heat treatment and surface modification processes. Topics to be covered include solutionizing, quenching, and carburization heat treatment. (Prerequisites: ME 4840 or MTE 511 and MTE 512 or equivalent.)

MTE 550. Phase Transformations in Materials

(3 credits)

This course is intended to provide a fundamental understanding of thermodynamic and kinetic principles associated with phase transformations. The mechanisms of phase transformations will be discussed in terms of driving forces to establish a theoretical background for various physical phenomena. The principles of nucleation and growth and spinodal transformations will be described. The theoretical analysis of diffusion controlled and interface controlled growth will be presented The basic concepts of martensitic transformations will be highlighted. Specific examples will include solidification, crystallization, precipitation, sintering, phase separation and transformation toughening. (Prerequisites: MTE 511 and MTE 512, ME 4850 or equivalent.)

MTE 556/ME 5356. Smart Materials

(2 credits)

A material whose properties can respond to an external stimulus in a controlled fashion is referred to as a smart or intelligent material. These materials can be made to undergo changes modulus, shape, porosity, electrical conductivity, physical form, opacity, and magnetic properties based on an external stimulus. The stimuli can include temperature, pH, specific molecules, light, magnetic field, voltage and stress. These stimuli-sensitive materials can be utilized as sensors and as vehicles for the controlled delivery of drugs and other biomolecules in medical applications. Smart materials are also becoming important in other biological areas such as bio-separation, biosensor design, tissue engineering, protein folding, and microfluidics. The use of stimuli-sensitive materials is receiving increasing attention in the development of damage tolerant smart structures in aerospace, marine, automotive and earth quake resistant buildings. The use of smart materials is being explored for a range of applications including protective coatings, corrosion barriers, intelligent batteries, fabrics and food packaging. The purpose of this course is to provide an introduction to the various types of smart

Return to Table of Contents

materials including polymers, ceramic, metallic alloys and composites. Fundamental principles associated with the onset of "smart" property will be highlighted. The principles of self-healable materials based on smart materials will be discussed. The application of smart materials in various fields including sensors, actuators, diagnostics, therapeutics, packaging and other advanced applications will be presented. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594).

MTE 558. Plastics

(2 credits)

This course will provide an integrated overview of the design, selection and use of synthetic plastics. The basic chemistry associated with polymerization and the structure of commercial plastics will be described. Various aspects of polymer crystallization and glass transition will be outlined. Salient aspects of fluid flow and heat transfer during the processing of plastics will be highlighted. Fundamentals of the diverse processing operations used to shape plastics and the resulting structures that develop after processing will be discussed. The mechanical behavior of plastics including elastic deformation, rubber elasticity, yielding, viscoelasticity, fracture and creep will be discussed. Plastic degradation and environmental issues associated with recycling and disposal of plastics will be examined. Typical techniques used in the analysis and testing of plastics will be described and a working knowledge of various terminologies used in commercial practice will be provided. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594A).

MTE 561/ME 5361. Mechanical Behavior and Fracture of Materials

(2 credits)

The failure and wear-out mechanisms for a variety of materials (metals, ceramics, polymers, composites and microelectronics) and applications will be presented and discussed. Multi-axial failure theories and fracture mechanics will be discussed. The methodology and techniques for reliability analysis will also be presented and discussed. A materials systems approach will be used. (Prerequisites: ES 2502 and ME 3023 or equivalent, and senior or graduate standing in engineering or science.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 593C/MTE 594C).

MTE 575/ME 4875. Introduction to Nanomaterials and Nanotechnology

(2 credits)

This course introduces students to current developments in nanoscale science and technology. The current advance of materials and devices constituting of building blocks of metals, semiconductors, ceramics or polymers that are nanometer size (1-100 nm) are reviewed. The profound implications for technology and science of this research field are discussed. The differences of the properties of matter on the nanometer scale from those on the macroscopic scale due to the size confinement, predominance of interfacial phenomena and quantum mechanics are studied. The main issues and techniques relevant to science and technologies on the nanometer scale are considered. New developments in this field and future perspectives are presented. Topics covered include: fabrication of nanoscale structures, characterization at nanoscale, molecular electronics, nanoscale mechanics, new architecture, nano optics and societal impacts. Recommended background: ES 2001 Introduction to Materials or equivalent

MTE 580. Materials Science and Engineering Seminar

Reports on the state-of-the-art in various areas of research and development in materials science and engineering will be presented by the faculty and outside experts. Reports on graduate student research in progress will also be required.

MTE 5816. Ceramics and Glasses for Engineering Applications

(2 credits)

This course develops an understanding of the processing, structure, property, performance relationships in crystalline and vitreous ceramics. The topics covered include crystal structure, glassy structure, phase diagrams, microstructures, mechanical properties, optical properties, thermal properties, and materials selection for ceramic materials. In addition the methods for processing ceramics for a variety of products will be included. Recommended background: ES2001 or equivalent. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

MTE/MFE 5841
ME 5370. Surface Metrology

(3 credits)

This course emphasizes research applications of advanced surface metrology, including the measurement and analysis of surface roughness. Surface metrology can be important in a wide variety of situations including adhesion, friction, catalysis, heat transfer, mass transfer, scattering, biological growth, wear and wetting. These situations impact practically all the engineering disciplines and sciences. The course begins by considering basic principles and conventional analyses, and methods. Measurement and analysis methods are critically reviewed for utility. Students learn advanced methods for differentiating surface textures that are suspected of being different because of their performance or manufacture. Students will also learn methods for making correlations between surface textures and behavioral and manufacturing parameters. The results of applying these methods can be used to support the design and manufacture of surface textures, and to address issues in quality assurance. Examples of research from a broad range of applications are presented, including, food science, pavements, friction, adhesion, machining and grinding. Students do a major project of their choosing, which can involve either an in-depth literature review, or surface measurement and analysis. The facilities of WPI's Surface Metrology Laboratory are available for making measurements for selected projects. Software for advanced analysis methods is also available for use in the course. No previous knowledge of surface metrology is required. Students should have some background in engineering, math or science.

MTE 5844. Corrosion and Corrosion Control

(2 credits)

An introductory course on corrosion; aqueous corrosion, stress corrosion cracking and hydrogen effects in metals will be presented. High-temperature oxidation, carburization and sulfidation will be discussed. Discussions focus on current corrosive engineering problems and research. (Prerequisites: MTE 511 and MTE 512 or consent of the instructor.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

MTE/ME 5847. Materials for Electrochemical Energy Systems

(2 credits)

An introductory course on electrochemical engineering, fuel cells and batteries. With escalating oil prices and increasing environmental concerns, increasing attention is being paid to the development of electrochemical devices to replace traditional energy. Here several types of batteries and fuel cells will be discussed. Topics covered include: basic electrochemistry, lithium ion battery, proton exchange membrane fuel cell, solid oxide fuel cell, electrochemical method. Recommended background: ES2001 or equivalent. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course.

MTE 594. Special Topics

(As arranged)

Theoretical or experimental studies in subjects of interest to graduate students in materials science and engineering.

Research

{As arranged)

Additional acceptable courses, 4000 series, may be found in the Undergraduate Catalog.

Mathematical Sciences

www.wpi.edu/+math

Faculty

L. Capogna, Professor and Head; Ph.D., Purdue University, 1996. Partial differential equations.

J. Abraham, Professor of Practice and Actuarial Mathematics Coordinator; Fellow, Society of Actuaries, 1991; B.S., University of Iowa, 1980.

A. Arnold, Assistant Professor; Ph.D., Case Western University, 2014. Mathematical biology, bayesian inference, parameter estimation in biological systems.

F. Bernardi, Assistant Professor; Ph.D., University of North Carolina at Chapel Hill, 2018. Small-scale fluid mechanics and microfluidics, in particular modeling particle transport and water filtration systems.

M. Blais, Teaching Associate Professor, Coordinator of Professional Science Master's Programs and Associate Department Head; Ph.D., Cornell University, 2005. Mathematical finance.

J. D. Fehribach, Professor; Ph.D., Duke University, 1985. Partial differential equations and scientific computing, free and moving boundary problems (crystal growth), nonequilibrium thermodynamics and averaging (molten carbonate fuel cells).

J. Goulet, Teaching Professor and Coordinator, Master of Mathematics for Educators Program; Ph.D., Rensselaer Polytechnic Institute, 1976. Applications of linear algebra, cross departmental course development, project development, K-12 relations with colleges, mathematics of digital and analog sound and music.

A. C. Heinricher, Professor; Ph.D., Carnegie Mellon University, 1986. Applied probability, stochastic processes and optimal control theory.

M. Humi, Professor; Ph.D., Weizmann Institute of Science, 1969. Mathematical physics, applied mathematics and modeling, Lie groups, differential equations, numerical analysis, turbulence and chaos.

M. Johnson, Teaching Associate Professor; Ph.D., Clark University 2012. Industrial organization, game theory.

C. J. Larsen, Professor; Ph.D., Carnegie Mellon University, 1996. Variational problems from applications such as optimal design, fracture mechanics, and image segmentation, calculus of variations, partial differential equations, geometric measure theory, analysis of free boundaries and free discontinuity sets.

R. Y. Lui, Professor; Ph.D., University of Minnesota, 1981. Mathematical biology, partial differential equations.

K. A. Lurie, Professor; Ph.D., 1964, D.Sc., 1972, A. F. Ioffe Physical-Technical Institute, Academy of Sciences of the USSR, Russia. Control theory for distributed parameter systems, optimization and nonconvex variational calculus, optimal design.

W. J. Martin, Professor; Ph.D., University of Waterloo, 1992. Algebraic combinatorics, applied combinatorics.

U. Mosco, H. J. Gay Professor; Libera Docenza, University of Rome, 1967. Partial differential equations, convex analysis, optimal control, variational calculus, fractals.

B. Nandram, Professor; Ph.D., University of Iowa, 1989. Survey sampling theory and methods, Bayes and empirical Bayes theory and methods, categorical data analysis.

P. O'Cathain, Assistant Professor; Ph.D., National University of Ireland, Galway, 2012. Combinatorics, algebra and compressed sensing.

S. Olson, Associate Professor; Ph.D., North Carolina State University 2008. Mathematical biology, computational biofluids, scientific computing.

R. C. Paffenroth, Associate Professor; Ph.D., University of Maryland, 1999. Large scale data analytics, statistical machine learning, compressed sensing, network analysis.

B. Peiris, Assistant Teaching Professor, Ph.D., Southern Illinois University, Carbondale, 2014. Bayesian Statistics, order restricted inference, meta-analysis.

G. Peng, Assistant Professor; Ph.D., Purdue University, 2014. Partial differential equations with a focus on applications to the sciences.

B. Posterro, Teaching Associate Professor; M.S., Financial Mathematics, Worcester Polytechnic Institute, 2010, M.S. Applied Mathematics, Worcester Polytechnic Institute, 2000.

A. Sales, Assistant Professor; Ph.D., University of Michigan, 2013. Methods for causal inference using administrative or high-dimensional data, especially in education.

M. Sarkis, Professor; Ph.D., Courant Institute of Mathematical Sciences, 1994. Domain decomposition methods, numerical analysis, parallel computing, computational fluid dynamics, preconditioned iterative methods for linear and non-linear problems, numerical partial differential equations, mixed and non-conforming finite methods, overlapping non-matching grids, mortar finite elements, eigenvalue solvers, aeroelasticity, porous media reservoir modeling.

B. Servatius, Professor; Ph.D., Syracuse University, 1987. Combinatorics, matroid and graph theory, structural topology, geometry, history and philosophy of mathematics.

S. Sturm, Associate Professor; Ph.D. TU Berlin 2010. Mathematical finance: stochastic volatility, optimal portfolio problems, systemic risk; stochastic analysis: backward stochastic differential equations, large deviations, Malliavin calculus.

D. Tang, Professor; Ph.D., University of Wisconsin, 1988. Biofluids, biosolids, blood flow, mathematical modeling, numerical methods, scientific computing, nonlinear analysis, computational fluid dynamics.

B. S. Tilley, Associate Professor; Ph.D., Northwestern University, 1994. Free-boundary problems in continuum mechanics, interfacial fluid dynamics, viscous flows, partial differential equations, mathematical modeling, asymptotic methods.

B. Vernescu, Professor; Ph.D., Institute of Mathematics, Bucharest, Romania, 1989. Partial differential equations, phase transitions and free-boundaries, viscous flow in porous media, asymptotic methods and homogenization.

Return to Table of Contents

D. Volkov, Associate Professor; Ph.D., Rutgers University, 2001. Electromagnetic waves, inverse problems, wave propagation in waveguides and in periodic structures, electrified fluid jets.

G. Wang, Assistant Professor; Ph.D., Boston University, 2013. Stochastic control, mathematical finance, stochastic analysis, applied probability.

S. Weekes, Professor; Ph.D., University of Michigan, 1995. Numerical analysis, computational fluid dynamics, porous media flow, hyperbolic conservation laws, shock capturing schemes.

M. Wu, Visiting Assistant Professor; Ph.D., University of California, Irvine, 2012. Mathematical biology, modeling of living systems.

Z. Wu, Associate Professor; Ph.D., Yale University, 2009. Biostatistics, high-dimensional model selection, linear and generalized linear modeling, statistical genetics, bioinformatics.

V. Yakovlev, Research Associate; Ph.D., Institute of Radio Engineering and Electronics, Russian Academy of Sciences, 1991. Antennas for MW and MMW communications, electromagnetic fields in transmission lines and along media interfaces, control and optimization of electromagnetic and temperature fields in microwave thermal processing, issues in modeling of microwave heating, computational electromagnetics with neural networks, numerical methods, algorithms and CAD tools for RF, MW and MMW components and subsystems.

Z. Zhang, Associate Professor; Ph.D., Brown University, 2014, Shanghai University, 2011. Numerical analysis, scientific computing, computational and applied mathematics, uncertainty qualification.

J. Zou, Associate Professor; Ph.D., University of Connecticut, 2009. Financial time series (especially high frequency financial data), spatial statistics, biosurveillance, high dimensional statistical inference, Bayesian statistics.

Emeritus

P. W. Davis, Professor

W. J. Hardell, Professor

J. J. Malone, Professor

B. C. McQuarrie, Professor

W. B. Miller, Professor

D. Vermes, Professor

Research Interests

Active areas of research in the Mathematical Sciences Department include applied and computational mathematics, industrial mathematics, applied statistics, scientific computing, numerical analysis, ordinary and partial differential equations, non-linear analysis, electric power systems, control theory, optimal design, composite materials, homogenization, computational fluid dynamics, biofluids, dynamical systems, free and moving boundary problems, porous media modeling, turbulence and chaos, mathematical physics, mathematical biology, operations research, linear and nonlinear programming, discrete mathematics, graph theory, group theory, linear algebra, combinatorics, applied probability, stochastic processes, time series analysis, Bayesian statistics, Bayesian computation, survey research methodology, categorical data analysis, Monte Carlo methodology, statistical computing, survival analysis and model selection.

Programs of Study

The Mathematical Sciences Department offers four programs leading to the degree of master of science, a combined B.S./Master's program, a program leading to the degree of master of mathematics for educators, and a program leading to the degree of doctor of philosophy.

Master of Science in Applied Mathematics Program

This program gives students a broad background in mathematics, placing an emphasis on areas with the highest demand in applications: numerical methods and scientific computation, mathematical modeling, discrete mathematics, mathematical materials science, optimization and operations research. In addition to these advanced areas of specialization, students are encouraged to acquire breadth by choosing elective courses in other fields that complement their studies in applied mathematics. Students have a choice of completing their master's thesis or project in cooperation with one of the department's established industrial partners. The program provides a suitable foundation for the pursuit of a Ph.D. degree in applied mathematics or a related field, or for a career in industry immediately after graduation.

Master of Science in Applied Statistics Program

This program gives graduates the knowledge and experience to tackle problems of statistical design, analysis and control likely to be encountered in business, industry or academia. The program is designed to acquaint students with the theory underlying modern statistical methods, to provide breadth in diverse areas of statistics and to give students practical experience through extensive application of statistical theory to real problems.

Through the selection of elective courses, the student may choose a program with an industrial emphasis or one with a more theoretical emphasis.

Professional Master of Science in Financial Mathematics Program

This program offers an efficient, practice-oriented track to prepare students for quantitative careers in the financial industry, including banks, insurance companies, and investment and securities firms. The program gives students a solid background and sufficient breadth in the mathematical and statistical foundations needed to understand the cutting edge techniques of today and to keep up with future developments in this rapidly evolving area over the span of their careers. It also equips students with expertise in quantitative financial modeling and the computational methods and skills that are used to implement the models. The mathematical knowledge is complemented by studies in financial management, information technology and/or computer science.

The bridge from the academic environment to the professional workplace is provided by a professional master's project that involves the solution of a concrete, real-world problem directly originating in the financial industry. Students are encouraged to complete summer internships at financial firms. The department may help students to find suitable financial internships through the industrial connections of faculty affiliated with the Center for Industrial Mathematics and Statistics. Graduates of the program are expected to start or advance their professional careers in such areas as financial product development and pricing, risk management, investment decision support and portfolio management.

Professional Master of Science in Industrial Mathematics Program

This is a practice-oriented program that prepares students for successful careers in industry. The graduates are expected to be generalized problem-solvers, capable of moving from task to task within an organization. In industry, mathematicians need not only the standard mathematical and statistical modeling and computational tools, but also knowledge within other areas of science or engineering. This program aims at developing the analytical, modeling and computational skills needed by mathematicians who work in industrial environments. It also provides the breadth required by industrial multidisciplinary team environments through courses in one area of science or engineering, e.g., physics, computer science, mechanical engineering, and electrical and computer engineering.

The connection between academic training and industrial experience is provided by an industrial professional master's project that involves the solution of a concrete, real-world problem originating in industry. The department, through the industrial connections of the faculty affiliated with the Center for Industrial Mathematics and Statistics, may help students identify and select suitable industrial internships. Graduates of the program are expected to start or advance their professional careers in industry.

Master of Mathematics for Educators (MME)

This is an evening and/or online program designed primarily for secondary school mathematics teachers. Courses offer a solid foundation in areas such as geometry, algebra, modeling, discrete math and statistics, while also including the study of modern applications. Additionally, students develop materials, based on coursework, which may be used in their classes. Technology is introduced when possible to give students exposure for future consideration. Examples include Geometer's Sketchpad; Maple for algebra, calculus and graphics; Matlab for analysis of sound and music; and the TI CBL for motion and heat.

Master of Science in Mathematics for Educators (MMED)

The Master of Science in Mathematics for Educators is designed specifically for middle school, high school and junior college in-service educators. The emphasis of the program is put on mathematics content coursework combined with courses in assessment and evaluation theory and a culminating project designed by the participant. The mathematics content courses, designed for educators, offer teachers a solid foundation in areas such as geometry, algebra, modeling, discrete math and statistics, while also including the study of modern applications. In these courses, participants have the opportunity to develop materials, based on coursework, which may be used in their classes. Throughout the courses, technology is introduced whenever possible to help educators become familiar with the options available for use in the classroom. Examples of this include Geometer's Sketchpad and the TI CBL for motion and heat. This combination of content courses, assessment and evaluation theory courses, and a final project are perfect for educators looking for a program that emphasizes mathematics and supports educators in learning how to better evaluate their effectiveness in the classroom. For information about admissions and requirements, see the listing under STEM for Educators.

Doctor of Philosophy in Mathematical Sciences Program

The goal of this program is to produce active and creative problem solvers, capable of contributing in academic and industrial environments. One distinguishing feature of this program is an optional Ph.D. project to be completed under the guidance of an external sponsor, e.g., from industry or a national research center. The intention of this project is to connect theoretical knowledge with relevant applications and to improve skills in applying and communicating mathematics.

Doctor of Philosophy in Statistics Program

The overall objective is to create a highly competitive program that produces future scholars and leaders in Statistics. The program will provide rigorous and comprehensive training in mathematics, statistics and related areas, as well as in critical thinking and problem solving for statistical challenges in data-related researches and applications. The goal is to prepare future leading statisticians in academia, industry, and government.

Combined B.S./Master's Program

This program allows a student to work concurrently toward bachelor and master of science degrees in applied mathematics, applied statistics, financial mathematics and industrial mathematics.

Admission Requirements

A basic knowledge of undergraduate analysis, linear algebra and differential equations is assumed for applicants to the master's programs in applied mathematics and industrial mathematics. A strong background in mathematics, which should include courses in undergraduate analysis and linear algebra, is assumed for applicants to the master's program in financial mathematics. Typically, an entering student in the master of science in applied statistics program will have an undergraduate major in the mathematical sciences, engineering or a physical science; however, individuals with other backgrounds will be considered. In any case, an applicant will need a strong background in mathematics, which should include courses in undergraduate analysis and probability. Students with serious deficiencies may be required to correct them on a noncredit basis. Applicants to the Mathematical Sciences Ph.D. Program should submit GRE Mathematics Subject Test scores if possible; an applicant who finds it difficult to submit a score is welcome to contact the Mathematical Sciences Department Graduate Admissions Committee (ma-questions@wpi.edu) to discuss the applicant's situation.

For the applicants to the Ph.D. Program in Statistics, strong background of undergraduate analysis, linear algebra

Return to Table of Contents

and probability is assumed; the GRE Mathematics Subject Test is recommended but not required.

Candidates for the master of mathematics for educators degree must have a bachelor's degree and must possess a background equivalent to at least a minor in mathematics, including calculus, linear algebra, and statistics. Students are encouraged to enroll in courses on an ad hoc basis without official program admission. However, (at most) four such courses may be taken prior to admission.

Degree Requirements

For the M.S. in Applied Mathematics

The master's program in Applied Mathematics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. The student's program must include at least seven MA numbered courses other than 501 or 511. Among these must be MA 503, MA 510, and either MA 535 or MA 530. In addition, students are required to complete a Capstone Experience, which can be satisfied by one of the following options:

(a) A six credit master's thesis.

(b) A three to six credit master's project.

(c) A three credit master's practicum.

(d) A three credit research review report or research proposal.

(e) A master's exam.

The master's thesis is an original piece of mathematical research work which focuses on advancing the state of the mathematical art. The master's project consists of a creative application of mathematics to a real-world problem. It focuses on problem definition and solution using mathematical tools. The master's practicum requires a student to demonstrate the integration of advanced mathematical concepts and methods into professional practice. This could be done through a summer internship in industry or an applied research laboratory.

The remaining courses may be chosen from the graduate offerings of the Mathematical Sciences Department. Upper-level undergraduate mathematics courses or a two-course graduate sequence in another department may be taken for graduate credit, subject to the approval of the departmental Graduate Committee. Candidates are required to successfully complete the graduate seminar MA 557.

For the M.S. in Applied Statistics

The master's program in Applied Statistics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. Courses taken must include MA 540, MA 541, MA 546, MA 547, 3 credits of MA 559 and at least three additional departmental statistics offerings: MA 509 and courses numbered 542 through 556. Students who can demonstrate a legitimate conflict in scheduling MA 559 will be assigned an alternative activity by the Mathematical Science Department Graduate Committee. In addition the student must complete a Capstone Experience, which can be satisfied by one of the following options:

(a) A six credit master's thesis.

(b) A three to six credit master's project.

(c) A three credit master's practicum.

(d) A three credit research review report or research proposal.

(e) A master's exam.

Upper-level undergraduate courses may be taken for graduate credit subject to the approval of the departmental Graduate Committee.

For the M.S. in Financial Mathematics

The master's program in Financial Mathematics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. The curriculum consists of the following components:

1. **6 credits from required foundation courses:**

   MA 529 Stochastic Processes **or** MA 503 Lebesgue Measure and Integration

   MA 528 Measure Theoretic Probability Theory **or** MA 540 Probability and Mathematical Statistics I

2. **12 credits from core financial mathematics courses:**

   MA 571 Financial Mathematics I

   MA 572 Financial Mathematics II

   MA 573 Computational Methods of Financial Mathematics

   MA 574 Portfolio Valuation and Risk Management

   MA 575 Market and Credit Risk Models and Management

3. **3 credits chosen from Mathematical Sciences graduate courses MA 502-590.**

   B.S./M.S. students can count undergraduate courses MA 4213 Risk Theory, MA 4214 Survival Models, MA 4235 Mathematical Optimization, MA 4237 Probabilistic Methods in Operations Research, MA 4451 Boundary Value Problems, MA 4473 Partial Differential Equations, MA 4632 Probability and Mathematical Statistics II towards electives

4. **6 credit block in one of the following complementary areas outside of the Mathematical Sciences Department: Financial Management, Information Technology, or Computer Science.**

   Students with a degree or substantial work experience in one of the above complementary areas can substitute them with other courses subject to prior approval by the graduate committee

   B.S./M.S. students can count suitable undergraduate courses towards the complementary area requirement according the number of credits of the corresponding graduate courses

   2 of the complementary area credits can be earned by taking MA 579 Financial Programming Workshop

5. **Capstone Project, which may be satisfied by one of the following options:**

   (a) A three to six credit master's project.

   (b) A three credit master's practicum.

   (c) A three credit capstone course in financial mathematics.

The master's project consists of a creative application of mathematics to a real-world problem originating in the financial industry. It focuses on problem definition and solution using mathematical tools. The master's practicum requires a student to demonstrate the integration of advanced mathematical concepts and methods into professional practice. This could be done through an approved summer internship in industry or an applied research laboratory. The capstone course in financial mathematics can be chosen from MA 572, MA 573, MA 574, or MA 575 and will be an enhanced version of the course with extra work assigned. Prior to the start of the capstone course, a student seeking to use the course to satisfy the requirement must declare this intention to the professor of the course.

6. **MA 562A and MA 562B Professional Master's Seminar** (for no credit)

For the M.S. in Industrial Mathematics

The master's program in Industrial Mathematics requires a minimum of 30 credit-hours of coursework. Additional credit from coursework may be required by the department depending on the student's background. Students must complete four foundation courses: MA 503, MA 510 and two courses out of MA 508, MA 509, MA 529 and MA 530. Students must also complete a 12-credit-hour module composed of two courses within the department and a sequence of two courses from one graduate program outside the Mathematical Sciences Department. The department offers a wide selection of modules to suit students' interest and expertise.

In addition, students are required to complete a 3-credit-hour elective from the Mathematical Sciences Department and a 3-credit-hour master's project on a problem originating from industry. Candidates are required to successfully complete the Professional Master's Seminars MA 562A and MA 562B. The Plan of Study and the project topic require prior approval by the departmental Graduate Committee.

Examples of Modules for the M.S. Degree in Industrial Mathematics

The courses comprising the 12-credit module should form a coherent sequence that provides exposure to an area outside of mathematics and statistics, providing at the same time the mathematical tools required by that particular area. Examples of typical modules are:

- Dynamics and control module—MA 512, MA 540, ME 5220, 5221, 5222, 5223;
- Materials module—MA 512, MA 526, and ME 5311;
- Fluid dynamics module—MA 512, MA 526, ME 511 and ME 5101, 5102, 5103;
- Biomedical engineering module—MA 512, MA 526, BME/ME 550 and BME/ME 552;
- Machine learning module—MA 540, MA 541, CS 509 and CS 539;
- Cryptography module—MA 533, MA 514, CS 503 and ECE 578.

For the Combined B.S./Master's Programs in Applied Mathematics and Applied Statistics

Credits from no more than four courses may be counted toward both the undergraduate and graduate degrees. All of these courses must be 4000-level or above, and at least one must be a graduate course. Three of them must be beyond the 7 units of mathematics required for the B.S. degree. Additionally, students are advised that all requirements of a particular master's program must be satisfied in order to receive the degree, and these courses should be selected accordingly.

Acceptance into the program means that the candidate is qualified for graduate school and signifies approval of the four courses to be counted for credit toward both degrees. However, in order to obtain both undergraduate and graduate credit for these courses, grades of B or better have to be obtained.

For the Master of Mathematics for Educators (M.M.E.)

Candidates for the Master of Mathematics for educators must successfully complete 30 credit hours of graduate study, including a 6-credit-hour project (see MME 592, MME 594, MME 596). This project will typically consist of a classroom study within the context of a secondary mathematics course and will be advised by faculty in the Mathematical Sciences Department. Typically, a student will enroll in 4 credit hours per semester during the fall and spring, with the remaining credit hours taken in the summer.

Students may complete the degree in as little as slightly over two years by taking two courses per semester, 3 semesters per year, and doing a project. However, the program can accommodate other completion schedules as well. The MME degree may be used to satisfy the Massachusetts Professional License requirement, provided the person holds an Initial License.

For the Master of Science in Mathematics for Educators (MMED)

For a complete overview of degree requirements, please see STEM for Educators.

For the Ph.D.

The course of study leading to the doctor of philosophy in mathematical science and the doctor of philosophy in statistics requires the completion of at least 90 credit hours beyond the bachelor's degree or at least 60 credit hours beyond the master's degree, as follows:

General Courses (credited for students with master's degrees)	30 credits
Research Preparation Phase	24-30 credits
Research-Related Courses or Independent Studies	9-18 credits
Ph.D. Project	1-9 credits
Extra-Departmental Studies	6 credits
Dissertation Research	at least 30 credits

A brief description of other Ph.D. program requirements follows below. For further details, students are advised to consult the document *Ph.D. Program Requirements and Administrative Rules for the Department of Mathematical Sciences*, available from the departmental graduate secretary.

Within a full-time student's first semester of study (second semester for part-time students), a Plan of Study leading to the Ph.D. degree must be submitted to the departmental Graduate Committee for review and approval. The Plan of Study may subsequently be modified with review by the departmental Graduate Committee.

Return to Table of Contents

Extra-Departmental Studies Requirement
A student must complete at least six semester hours of courses, 500 level or higher, in WPI departments other than the Mathematical Sciences Department.

General Comprehensive Examination
A student must pass the general comprehensive examination (GCE) in order to become a Ph.D. candidate. The purpose of the GCE is to determine whether a student possesses the fundamental knowledge and skills necessary for study and research at the Ph.D. level. It is a written examination offered three times a year, once each in January, May, and August. A student must pass by January of their second year if they enter in the fall, and May of their second year if they enter in the spring.

Mathematical Sciences Ph.D. Project
A student may complete a Ph.D. project involving a problem originating with a sponsor external to the department. The purposes of the project are to broaden perspectives on the relevance and applications of mathematics and to improve skills in communicating mathematics and formulating and solving mathematical problems. Students are encouraged to work with industrial sponsors on problems involving applications of the mathematical sciences. Each Ph.D. project requires prior approval by the project advisor, the external sponsor, and the departmental Graduate Committee.

Ph.D. Preliminary Examination
Successful completion of the preliminary examination is required before a student can register for dissertation research credits. The purpose of the preliminary examination is to determine whether a student's understanding of advanced areas of mathematics is adequate to conduct independent research and successfully complete a dissertation. The preliminary examination consists of both written and oral parts. A full-time student must make the first attempt by the end of his or her third year (sixth year for part-time students) in the Ph.D. program.

Ph.D. Dissertation
The Ph.D. dissertation is a significant work of original research conducted under the supervision of a dissertation advisor, who is normally a member of the departmental faculty. The dissertation advisor chairs the student's dissertation committee, which consists of at least five members, including one recognized expert external to the department, and which must be approved by the departmental Graduate Committee. At least six months prior to completion of the dissertation, a student must submit a written dissertation proposal and present a public seminar on the research plan described in the proposal. The proposal must be approved by the dissertation committee. Upon completion of the dissertation and other program requirements, the student presents the dissertation to the dissertation committee and to the general community in a public oral defense. The dissertation committee determines whether the dissertation is acceptable.

Unsatisfactory Progress
If the aforementioned milestones are not met, then the student must petition the graduate program committee to request extra time to meet the requirements or the student will be no longer be part of the Ph.D. program as of the following semester.

Mathematical Sciences Computer Facilities
The Mathematical Sciences Department makes up-to-date computing equipment available for use by students in its programs.

Current facilities include a mixed environment of approximately 85 Windows, Linux/Unix and Macintosh workstations utilizing the latest in single- and dual- processor 32 and 64 bit technology as well as 4 Bloomberg terminals. Access is available to our supercomputer, a 16 CPU SGI Altix 350. The Mathematical Sciences Department also has 3 state-of-the-art computer labs, one each dedicated to the Calculus, Statistics, and Financial Mathematics programs.

The department is continually adding new resources to give our faculty and students the tools they need as they advance in their research and studies.

Center for Industrial Mathematics and Statistics (CIMS)
www.wpi.edu/+CIMS

The Center for Industrial Mathematics and Statistics was established in 1997 to foster partnerships between the university and industry, business and government in mathematics and statistics research.

The problems facing business and industry are growing ever more complex, and their solutions often involve sophisticated mathematics. The faculty members and students associated with CIMS have the expertise to address today's complex problems and provide solutions that use relevant mathematics and statistics.

The Center offers undergraduates and graduate students the opportunity to gain real-world experience in the corporate world through projects and internships that make them more competitive in today's job market. In addition, it helps companies address their needs for mathematical solutions and enhances their technological competitiveness.

The industrial projects in mathematics and statistics offered by CIMS provide a unique education for successful careers in industry, business and higher education.

Course Descriptions
All courses are 3 credits unless otherwise noted.

Mathematical Sciences
MA 500. Basic Real Analysis
This course covers basic set theory, topology of Rn, continuous functions, uniform convergence, compactness, infinite series, theory of differentiation and integration. Other topics covered may include the inverse and implicit function theorems and Riemann-Stieltjes integration. Students may not count both MA 3831 and MA 500 toward their undergraduate degree requirements.

MA 501. Engineering Mathematics
This course develops mathematical techniques used in the engineering disciplines. Preliminary concepts will be reviewed as necessary, including vector spaces, matrices and eigenvalues. The principal topics covered will include vector calculus, Fourier transforms, fast Fourier transforms and Laplace transformations. Applications of these

techniques for the solution of boundary value and initial value problems will be given. The problems treated and solved in this course are typical of those seen in applications and include problems of heat conduction, mechanical vibrations and wave propagation. (Prerequisite: A knowledge of ordinary differential equations, linear algebra and multivariable calculus is assumed.)

MA 502. Linear Algebra
This course provides an introduction to the theory and methods of applicable linear algebra. The goal is to bring out the fundamental concepts and techniques that underlie and unify the many ways in which linear algebra is used in applications. The course is suitable for students in mathematics and other disciplines who wish to obtain deeper insights into this very important subject than are normally offered in undergraduate courses. It is also intended to provide a foundation for further study in subjects such as numerical linear algebra and functional analysis.

MA 503. Lebesgue Measure and Integration
This course begins with a review of topics normally covered in undergraduate analysis courses: open, closed and compact sets; liminf and limsup; continuity and uniform convergence. Next the course covers Lebesgue measure in R^n including the Cantor set, the concept of a sigma-algebra, the construction of a nonmeasurable set, measurable functions, semicontinuity, Egorov's and Lusin's theorems, and convergence in measure. Next we cover Lebesgue integration, integral convergence theorems (monotone and dominated), Tchebyshev's inequality and Tonelli's and Fubini's theorems. Finally L^p spaces are introduced with emphasis on L^2 as a Hilbert space. Other related topics will be covered at the instructor's discretion. (Prerequisite: Basic knowledge of undergraduate analysis is assumed.)

MA 504. Functional Analysis
This course will give a comprehensive presentation of fundamental concepts and theorems in Banach and Hilbert spaces. Whenever possible, the theory will be illustrated by examples in Lebesgue spaces. Topics include: The Hahn-Banach theorems, the Uniform Boundedness principle (Banach-Steinhaus Theorem), the Open Mapping and Closed Graph theorems, and weak topologies and convergence. Additional topics will be covered at the instructor's discretion. (Prerequisite: MA 503 or equivalent.)

MA 505. Complex Analysis
This course will provide a rigorous and thorough-treatment of the theory of functions of one complex variable. The topics to be covered include complex numbers, complex differentiation, the Cauchy-Riemann equations, analytic functions, Cauchy's theorem, complex integration, the Cauchy integral formula, Liouville's theorem, the Gauss mean value theorem, the maximum modulus theorem, Rouche's theorem, the Poisson integral formula, Taylor-Laurent expansions, singularity theory, conformal mapping with applications, analytic continuation, Schwarz's reflection principle and elliptic functions. (Prerequisite: knowledge of undergraduate analysis.)

MA 508. Mathematical Modeling
This course introduces mathematical model-building using dimensional analysis, perturbation theory and variational principles. Models are selected from the natural and social sciences according to the interests of the instructor and students. Examples are: planetary orbits, spring-mass systems, fluid flow, isomers in organic chemistry, biological competition, biochemical kinetics and physiological flow. Computer simulation of these models will also be considered. (Prerequisite: knowledge of ordinary differential equations and of analysis at the level of MA 501 is assumed.)

MA 509. Stochastic Modeling
This course gives students a background in the theory and methods of probability, stochastic processes and statistics for applications. The course begins with a brief review of basic probability, discrete and continuous random variables, expectations, conditional probability and basic statistical inference. Topics covered in greater depth include generating functions, limit theorems, basic stochastic processes, discrete and continuous time Markov chains, and basic queuing theory including M/M/1 and M/G/1 queues. (Prerequisite: knowledge of basic probability at the level of MA 2631 and statistics at the level of MA 2612 is assumed.) This course is offered by special arrangement only, based on expressed student interest.

MA 510/CS 522. Numerical Methods
This course provides an introduction to a broad range of modern numerical techniques that are widely used in computational mathematics, science, and engineering. It is suitable for both mathematics majors and students from other departments. It covers introductory-level material for subjects treated in greater depth in MA 512 and MA 514 and also topics not addressed in either of those courses.

Subject areas include numerical methods for systems of linear and nonlinear equations, interpolation and approximation, differentiation and integration, and differential equations. Specific topics include basic direct and iterative methods for linear systems; classical rootfinding methods; Newton's method and related methods for nonlinear systems; fixed-point iteration; polynomial, piecewise polynomial, and spline interpolation methods; least-squares approximation; orthogonal functions and approximation; basic techniques for numerical differentiation; numerical integration, including adaptive quadrature; and methods for initial-value problems for ordinary differential equations. Additional topics may be included at the instructor's discretion as time permits.

Both theory and practice are examined. Error estimates, rates of convergence, and the consequences of finite precision arithmetic are also discussed. Topics from linear algebra and elementary functional analysis will be introduced as needed. These may include norms and inner products, orthogonality and orthogonalization, operators and projections, and the concept of a function space. (Prerequisite: knowledge of undergraduate linear algebra and differential equations is assumed, as is familiarity with MATLAB or a higher-level programming language.)

MA 511. Applied Statistics for Engineers and Scientists
This course is an introduction to statistics for graduate students in engineering and the sciences. Topics covered include basic data analysis, issues in the design of studies, an introduction to probability, point and interval estimation and hypothesis testing for means and proportions from one and two samples, simple and multiple regression, analysis of one and two-way tables, one-way analysis of variance. As time permits, additional topics, such as distribution-free methods and the design and analysis of factorial studies will be considered. (Prerequisites: Integral and differential calculus.)

MA 512. Numerical Differential Equations
This course begins where MA 510 ends in the study of the theory and practice of the numerical solution of differential equations. Central topics include a review of initial value problems, including Euler's method, Runge-Kutta methods, multi-step methods, implicit methods and predictor-corrector methods; the solution of two-point boundary value problems by shooting methods and by the discretization of the original problem to form systems of nonlinear equations; numerical stability; existence and uniqueness of solutions; and an introduction to the solution of partial differential equations by finite differences. Other topics might include finite element or boundary element methods, Galerkin methods, collocation, or variational methods. (Prerequisites: graduate or undergraduate numerical analysis. Knowledge of a higher-level programming language is assumed.)

MA 514. Numerical Linear Algebra
This course provides students with the skills necessary to develop, analyze and implement computational methods in linear algebra. The central topics include vector and matrix algebra, vector and matrix norms, the singular value decomposition, the LU and QR decompositions, Householder transformations and Givens rotations, and iterative methods for solving linear systems including Jacobi, Gauss-Seidel, SOR and conjugate gradient methods; and eigenvalue problems. Applications to such problem areas as least squares and optimization will be discussed. Other topics might include: special linear systems, such as symmetric, positive definite, banded or sparse systems; preconditioning; the Cholesky decomposition; sparse tableau and other least-square methods; or algorithms for parallel architectures. (Prerequisite: basic knowledge of linear algebra or equivalent background. Knowledge of a higher-level programming language is assumed.)

Return to Table of Contents

MA/DS 517. Mathematical Foundations for Data Science

The foci of this class are the essential statistics and linear algebra skills required for Data Science students. The class builds the foundation for theoretical and computational abilities of the students to analyze high dimensional data sets. Topics covered include Bayes' theorem, the central limit theorem, hypothesis testing, linear equations, linear transformations, matrix algebra, eigenvalues and eigenvectors, and sampling techniques, including Bootstrap and Markov chain Monte Carlo. Students will use these techniques while engaging in hands-on projects with real data. Prerequisites: Some knowledge of integral and differential calculus is recommended.

MA 520. Fourier Transforms and Distributions

The course will cover L^1, L^2, L^∞ and basic facts from Hilbert space theory (Hilbert basis, projection theorems, Riesz theory). The first part of the course will introduce Fourier series: the L^2 theory, the C^∞ theory: rate of convergence, Fourier series of real analytic functions, application to the trapezoidal rule, Fourier transforms in L^1, Fourier integrals of Gaussians, the Schwartz class S, Fourier transforms and derivatives, translations, convolution, Fourier transforms in L^2, and characteristic functions of probability distribution functions. The second part of the course will cover tempered distributions and applications to partial differential equations. Other related topics will be covered at the instructor's discretion. (Prerequisite: MA 503.)

MA 521. Partial Differential Equations

This course considers a variety of material in partial differential equations (PDE). Topics covered will be chosen from the following: classical linear elliptic, parabolic and hyperbolic equations and systems, characteristics, fundamental/Green's solutions, potential theory, the Fredholm alternative, maximum principles, Cauchy problems, Dirichlet/Neumann/Robin problems, weak solutions and variational methods, viscosity solutions, nonlinear equations and systems, wave propagation, free and moving boundary problems, homogenization. Other topics may also be covered. (Prerequisites: MA 503 or equivalent.)

MA 522. Hilbert Spaces and Applications to PDE

The course covers Hilbert space theory with special emphasis on applications to linear ODs and PDEs. Topics include spectral theory for linear operators in n-dimensional and infinite dimensional Hilbert spaces, spectral theory for symmetric compact operatos, linear and bilinear forms, Riesz and Lax-Milgram theorems, weak derivatives, Sobolev spaces H^1, H^2, Rellich compactness theorem, weak and classical solutions for Dirichlet and Neumann problems in one variable and in Rn, Dirichlet variational principle, eigenvalues and eigenvectors. Other related topics will be covered at the instructor's discretion. (Prerequisite: MA 503.)

MA 524. Convex Analysis and Optimization

This course covers topics in functional analysis that are critical to the study of convex optimization problems. The first part of the course will include the minimization theory for quadratic and convex functionals on convex sets and cones, the Legendre-Fenchel duality, variational inequalities and complementarity systems. The second part will include optimal stopping time problems in deterministic control, value functions and Hamilton-Jacobi inequalities and linear and quadratic programming, duality and Kuhn-Tucker multipliers. Other related topics will be covered at the instructor's discretion. (Prerequisite: MA 503.)

MA 525. Optimal Control and Design with Composite Materials I

Modern technology involves a wide application of materials with internal structure adapted to environmental demands. This, the first course in a two-semester sequence, will establish a theoretical basis for identifying structures that provide optimal response to prescribed external factors. Material covered will include basics of the calculus of variations: Euler equations; transversality conditions; Weierstrass-Erdmann conditions for corner points; Legendre, Jacobi and Weierstrass conditions; Hamiltonian form of the necessary conditions; and Noether's theorem. Pontryagin's maximum principle in its original lumped parameter form will be put forth as well as its distributed parameter extension. Chattering regimes of control and relaxation through composites will be introduced at this point. May be offered by special arrangement.

MA 526. Optimal Control and Design with Composite Materials II

Topics presented will include basics of homogenization theory. Bounds on the effective properties of composites will be established using the translation method and Hashin-Shtrikman variational principles. The course concludes with a number of examples demonstrating the use of the theory in producing optimal structural designs. The methodology given in this course turns the problem of optimal design into a problem of rigorous mathematics. This course can be taken independently or as the sequel to MA 525.

MA 528. Measure Theoretic Probability Theory

This course is designed to give graduate students interested in financial mathematics and stochastic analysis the necessary background in measure-theoretic probability and provide a theoretical foundation for Ph.D. students with research interests in analysis and mathematical statistics. Besides classical topics such as the axiomatic foundations of probability, conditional probabilities and independence, random variables and their distributions, and limit theorems, this course focuses on concepts crucial for the understanding of stochastic processes and quantitative finance: conditional expectations, filtrations and martingales as well as change of measure techniques and the Radon-Nikodym theorem. A wide range of illustrative examples from a topic chosen by the instructor's discretion (e.g financial mathematics, signal processing, actuarial mathematics) will be presented. (Prerequisite: MA 500 Basic Real Analysis or equivalent.)

MA 529. Stochastic Processes

This course is designed to introduce students to continuous-time stochastic processes. Stochastic processes play a central role in a wide range of applications from signal processing to finance and also offer an alternative novel viewpoint to several areas of mathematical analysis, such as partial differential equations and potential theory. The main topics for this course are martingales, maximal inequalities and applications, optimal stopping and martingale convergence theorems, the strong Markov property, stochastic integration, Ito's formula and applications, martingale representation theorems, Girsanov's theorem and applications, and an introduction to stochastic differential equations, the Feynman-Kac formula, and connections to partial differential equations. Optional topics (at the instructor's discretion) include Markov processes and Poisson-and jump-processes. (Prerequisite: MA 528. Measure-Theoretic Probability Theory, which can be taken concurrently (or, with special permission by the instructor, MA 540)).

MA 530. Discrete Mathematics

This course provides the student of mathematics or computer science with an overview of discrete structures and their applications, as well as the basic methods and proof techniques in combinatorics. Topics covered include sets, relations, posets, enumeration, graphs, digraphs, monoids, groups, discrete probability theory and propositional calculus. (Prerequisites: college math at least through calculus. Experience with recursive programming is helpful, but not required.)

MA 533. Discrete Mathematics II

This course is designed to provide an in-depth study of some topics in combinatorial mathematics and discrete optimization. Topics may vary from year to year. Topics covered include, as time permits, partially ordered sets, lattices, matroids, matching theory, Ramsey theory, discrete programming problems, computational complexity of algorithms, branch and bound methods.

MA 535. Algebra

Fundamentals of group theory: homomorphisms and the isomorphism theorems, finite groups, structure of finitely generated Abelian groups. Structure of rings: homomorphisms, ideals, factor rings and the isomorphism theorems, integral domains, factorization. Field theory: extension fields, finite fields, theory of equations. Selected topics from: Galois theory, Sylow theory, Jordan-Hölder theory, Polya theory, group presentations, basic representation theory and group characters, modules. Applications chosen from mathematical physics, Gröbner bases, symmetry, cryptography, error-correcting codes, number theory.

MA 540/4631. Probability and Mathematical Statistics I

Intended for advanced undergraduates and beginning graduate students in the mathematical sciences, and for others intending to pursue the mathematical study of probability and statistics. Topics covered include axiomatic foundations, the calculus of probability, conditional probability and independence, Bayes' Theorem, random variables, discrete and continuous distributions, joint, marginal and conditional distributions, covariance and correlation, expectation, generating functions, exponential families, transformations of random variables, types of convergence, laws of large numbers the Central Limit Theorem, Taylor series expansion, the delta method. (Prerequisite: knowledge of basic probability at the level of MA 2631 and of advanced calculus at the level of MA 3831/3832 is assumed.)

MA 541/4632. Probability and Mathematical Statistics II

This course is designed to provide background in principles of statistics. Topics covered include estimation criteria: method of moments, maximum likelihood, least squares, Bayes, point and interval estimation, Fisher's information, Cramer-Rao lower bound, sufficiency, unbiasedness, and completeness, Rao-Blackwell Theorem, efficiency, consistency, interval estimation pivotal quantities, Neyman-Person Lemma, uniformly most powerful tests, unbiased, invariant and similar tests, likelihood ratio tests, convex loss functions, risk functions, admissibility and minimaxity, Bayes decision rules. (Prerequisite: knowledge of the material in MA 540 is assumed.)

MA 542. Regression Analysis

Regression analysis is a statistical tool that utilizes the relation between a response variable and one or more predictor variables for the purposes of description, prediction and/or control. Successful use of regression analysis requires an appreciation of both the theory and the practical problems that often arise when the technique is employed with real-world data. Topics covered include the theory and application of the general linear regression model, model fitting, estimation and prediction, hypothesis testing, the analysis of variance and related distribution theory, model diagnostics and remedial measures, model building and validation, and generalizations such as logistic response models and Poisson regression. Additional topics may be covered as time permits. Application of theory to real-world problems will be emphasized using statistical computer packages. (Prerequisite: knowledge of probability and statistics at the level of MA 511 and of matrix algebra is assumed.)

MA 543/DS 502. Statistical Methods for Data Science

Statistical Methods for Data Science surveys the statistical methods most useful in data science applications. Topics covered include predictive modeling methods, including multiple linear regression, and time series, data dimension reduction, discrimination and classification methods, clustering methods, and committee methods. Students will implement these methods using statistical software. Prerequisites: Statistics at the level of MA 2611 and MA 2612 and linear algebra at the level of MA 2071.

MA 546. Design and Analysis of Experiments

Controlled experiments—studies in which treatments are assigned to observational units—are the gold standard of scientific investigation. The goal of the statistical design and analysis of experiments is to (1) identify the factors which most affect a given process or phenomenon; (2) identify the ways in which these factors affect the process or phenomenon, both individually and in combination; (3) accomplish goals 1 and 2 with minimum cost and maximum efficiency while maintaining the validity of the results. Topics covered in this course include the design, implementation and analysis of completely randomized complete block, nested, split plot, Latin square and repeated measures designs. Emphasis will be on the application of the theory to real data using statistical computer packages. (Prerequisite: knowledge of basic probability and statistics at the level of MA 511 is assumed.)

MA 547. Design and Analysis of Observational and Sampling Studies

Like controlled experiments, observational studies seek to establish cause-effect relationships, but unlike controlled experiments, they lack the ability to assign treatments to observational units. Sampling studies, such as sample surveys, seek to characterize aspects of populations by obtaining and analyzing samples from those populations. Topics from observational studies include: prospective and retrospective studies; overt and hidden bias; adjustments by stratification and matching. Topics from sampling studies include: simple random sampling and associated estimates for means, totals, and proportions; estimates for subpopulations; unequal probability sampling; ratio and regression estimation; stratified, cluster, systematic, multistage, double sampling designs, and, time permitting, topics such as model-based sampling, spatial and adaptive sampling. (Prerequisite: knowledge of basic probability and statistics, at the level of MA 511 is assumed.)

MA 548. Quality Control

This course provides the student with the basic statistical tools needed to evaluate the quality of products and processes. Topics covered include the philosophy and implementation of continuous quality improvement methods, Shewhart control charts for variables and attributes, EWMA and Cusum control charts, process capability analysis, factorial and fractional factorial experiments for process design and improvement, and response surface methods for process optimization. Additional topics will be covered as time permits. Special emphasis will be placed on realistic applications of the theory using statistical computer packages. (Prerequisite: knowledge of basic probability and statistic, at the level of MA 511 is assumed.)

MA 549. Analysis of Lifetime Data

Lifetime data occurs frequently in engineering, where it is known as reliability or failure time data, and in the biomedical sciences, where it is known as survival data. This course covers the basic methods for analyzing such data. Topics include: probability models for lifetime data, censoring, graphical methods of model selection and analysis, parametric and distribution-free inference, parametric and distribution-free regression methods. As time permits, additional topics such as frailty models and accelerated life models will be considered. Special emphasis will be placed on realistic applications of the theory using statistical computer packages. (Prerequisite: knowledge of basic probability and statistics at the level of MA 511 is assumed.)

MA 550. Time Series Analysis

Time series are collections of observations made sequentially in time. Examples of this type of data abound in many fields ranging from finance to engineering. Special techniques are called for in order to analyze and model these data. This course introduces the student to time and frequency domain techniques, including topics such as autocorrelation, spectral analysis, and ARMA and ARIMA models, Box-Jenkins methodology, fitting, forecasting, and seasonal adjustments. Time permitting, additional topics will be chosen from: Kalman filter, smoothing techniques, Holt-Winters procedures, FARIMA and GARCH models, and joint time-frequency methods such as wavelets. The emphasis will be in application to real data situations using statistical computer packages. (Prerequisite: knowledge of MA 511 is assumed. Knowledge of MA 541 is also assumed, but may be taken concurrently.)

MA 552. Distribution-Free and Robust Statistical Methods

Distribution-free statistical methods relax the usual distributional modeling assumptions of classical statistical methods. Robust methods are statistical procedures that are relatively insensitive to departures from typical assumptions, while retaining the expected behavior when assumptions are satisfied. Topics covered include, time permitting, order statistics and ranks; classical distribution-free tests such as the sign, Wilcoxon signed rank, and Wilcoxon rank sum tests, and associated point estimators and confidence intervals; tests pertaining to one and two-way layouts; the Kolmogorov-Smirnov test; permutation methods; bootstrap and Monte Carlo methods; M, L, and R estimators, regression, kernel density estimation and other smoothing methods. Comparisons will be made to standard parametric methods. (Prerequisite: knowledge of MA 541 is assumed, but may be taken concurrently.)

MA 554. Applied Multivariate Analysis

This course is an introduction to statistical methods for analyzing multivariate data. Topics covered are multivariate sampling distributions, tests and estimation of multivariate normal parameters, multivariate ANOVA, regression, discriminant analysis, cluster analysis, factor analysis and principal components. Additional topics will be covered as time permits. Students will be required to analyze real data using one of the standard packages available. (Prerequisite: knowledge of MA 541 is assumed, but may be taken concurrently. Knowledge of matrix algebra is assumed.)

MA 556. Applied Bayesian Statistics

Bayesian statistics makes use of an inferential process that models data summarizing the results in terms of probability distributions for the model parameters. A key feature is that in the Bayesian approach, past information can be updated with new data in an elegant way in order to aid in decision making. Topics included in the courses: statistical decision theory, the Bayesian inferential framework (model specification, model fitting and model checking); computational methods for posterior simulation integration; regression models, hierarchical models, and ANOVA; time permitting, additional topics will include generalized linear models, multivariate models, missing data problems, and time series analysis. (Prerequisites: knowledge of MA 541 is assumed.)

MA 557 Graduate Seminar in Analysis and Applied Mathematics

(1 credit)

This seminar introduces students to modern issues in Analysis and Applied Mathematics. During the seminar, students and faculty will present and discuss recent research papers from the literature. Students will gain insights about current advances In the mathematical sciences and their applications.

MA 559. Statistics Graduate Seminar

(1 credit)

This seminar introduces students to issues and trends in modern statistics. In the seminar, students and faculty will read and discuss survey and research papers, make and attend presentations, and participate in brainstorming sessions toward the solution of advanced statistical problems.

MA 560. Graduate Seminar

(0 credits)

Designed to introduce graduate students to study of original papers and afford them opportunity to give account of their work by talks in the seminar.

MA 562 A and B. Professional Master's Seminar

(0 credits)

This seminar will introduce professional master's students to topics related to general writing, presentation, group communication and interviewing skills, and will provide the foundations to successful cooperation within interdisciplinary team environments. All full-time students will be required to take both components A and B of the seminar during their professional master's studies.

MA 571. Financial Mathematics I

This course provides an introduction to many of the central concepts in mathematical finance. The focus of the course is on arbitrage-based pricing of derivative securities. Topics include stochastic calculus, securities markets, arbitrage-based pricing of options and their uses for hedging and risk management, forward and futures contracts, European options, American options, exotic options, binomial stock price models, the Black-Scholes-Merton partial differential equation, risk-neutral option pricing, the fundamental theorems of asset pricing, sensitivity measures ("Greeks"), and Merton's credit risk model. (Prerequisite: MA 540, which can be taken concurrently.)

MA 572. Financial Mathematics II

The course is devoted to the mathematics of fixed income securities and to the financial instruments and methods used to manage interest rate risk. The first topics covered are the term-structure of interest rates, bonds, futures, interest rate swaps and their uses as investment or hedging tools and in asset-liability management. The second part of the course is devoted to dynamic term-structure models, including risk-neutral interest rate trees, the Heath-Jarrow-Morton model, Libor market models, and forward measures. Applications of these models are also covered, including the pricing of non-linear interest rate derivatives such as caps, floors, collars, swaptions and the dynamic hedging of interest rate risk. The course concludes with the coverage of mortgage-backed and asset-backed securities. (Prerequisite: MA 571.)

MA 573. Computational Methods of Financial Mathematics

Most realistic quantitative finance models are too complex to allow explicit analytic solutions and are solved by numerical computational methods. The first part of the course covers the application of finite difference methods to the partial differential equations and interest rate models arising in finance. Topics included are explicit, implicit and Crank-Nicholson finite difference schemes for fixed and free boundary value problems, their convergence and stability. The second part of the course covers Monte Carlo simulation methods, including random number generation, variance reduction techniques and the use of low discrepancy sequences. (Prerequisites: MA 571 and programming skills at the level of MA 579, which can be taken concurrently.)

MA 574. Portfolio Valuation and Risk Management

Balancing financial risks vs returns by the use of asset diversification is one of the fundamental tasks of quantitative financial management. This course is devoted to the use of mathematical optimization and statistics to allocate assets, to construct and manage portfolios and to measure and manage the resulting risks. The fist part of the course covers Markowitz's mean-variance optimization and efficient frontiers, Sharpe's single index and capital asset pricing models, arbitrage pricing theory, structural and statistical multi-factor models, risk allocation and risk budgeting. The second part of the course is devoted to the intertwining of optimization and statistical methodologies in modern portfolio management, including resampled efficiency, robust and Bayesian statistical methods, the Black-Litterman model and robust portfolio optimization.

MA 575. Market and Credit Risk Models and Management

The objective of the course is to familiarize students with the most important quantitative models and methods used to measure and manage financial risk, with special emphasis on market and credit risk. The course starts with the introduction of metrics of risk such as volatility, value-at-risk and expected shortfall and with the fundamental quantitative techniques used in financial risk evaluation and management. The next section is devoted to market risk including volatility modeling, time series, non-normal heavy tailed phenomena and multivariate notions of codependence such as copulas, correlations and tail-dependence. The final section concentrates on credit risk including structural and dynamic models and default contagion and applies the mathematical tools to the valuation of default contingent claims including credit default swaps, structured credit portfolios and collateralized debt obligations. (Prerequisite: knowledge of MA 540 assumed but can be taken concurrently.)

MA 579. Financial Programming Workshop

(1 or 2 credits)

The objective is to elevate the students' computer programming skills to the semi-professional level required in quantitative finance. Participants learn through hands-on experience by working on a structured set of mini projects from computational finance under the guidance of an experienced trainer and the faculty in charge. The programming language used may be C++, MATLAB, R/S, VB or another language widely used in quantitative finance and may alternate from year to year. (Prerequisite: Intermediate scientific programming skills.)

MA 584/BCB 504. Statistical Methods in Genetics and Bioinformatics

This course provides students with knowledge and understanding of the applications of statistics in modern genetics and bioinformatics. The course generally covers population genetics, genetic epidemiology, and statistical models in bioinformatics. Specific topics include meiosis modeling, stochastic models for recombination, linkage and association studies (parametric vs. nonparametric models, family-based vs. population-based models) for mapping genes of qualitative and quantitative traits, gene expression data analysis, DNA and protein sequence analysis, and molecular evolution. Statistical approaches include log-likelihood ratio tests, score tests, generalized linear models, EM algorithm, Markov chain Monte Carlo, hidden Markov model, and classification and regression trees. Students may not receive credit for both MA 584 and MA 4603. (Prerequisite: knowledge of probability and statistics at the undergraduate level.)

MA 590. Special Topics

Courses on special topics are offered under this number. Contact the Mathematical Sciences Department for current offerings.

MA 595. Independent Study

(1 to 3 credits)

Supervised independent study of a topic of mutual interest to the instructor and the student.

MA 596. Master's Capstone

(1 or more credits)

The Master's Capstone is designed to integrate classroom learning with real-world practice. It can consist of a project, a practicum, a research review report or a research proposal. A written report and a presentation are required.

MA 598. Professional Master's Project

(1 or more credits)

This project will provide the opportunity to apply and extend the material studied in the coursework to the study of a real-world problem originating in the industry. The project will be a capstone integrating industrial experience with the previously acquired academic knowledge and skills. The topic of the project will come from a problem generated in industry, and could originate from prior internship or industry experience of the student. The student will prepare a written project report and make a presentation before a committee including the faculty advisor, at least one additional WPI faculty member and representatives of a possible industrial sponsor. The advisor of record must be a faculty member of the WPI Mathematical Sciences Department. The student must submit a written project proposal for approval by the Graduate Committee prior to registering for the project.

MA 599. Thesis

(1 or more credits)

Research study at the master's level.

MA 698. Ph.D. Project

(1 or more credits)

Ph.D. project work.

MA 699. Dissertation

(1 or more credits)

Research study at the Ph.D. level.

Mathematics for Educators

MME 518. Geometrical Concepts

This course focuses primarily on the foundations and applications of Euclidean and non-Euclidean geometries. The rich and diverse nature of the subject also implies the need to explore other topics, for example, chaos and fractals. The course incorporates collaborative learning and the investigation of ideas through group projects. Possible topics include geometrical software and computer graphics, tiling and tessellations, two- and three-dimensional geometry, inversive geometry, graphical representations of functions, model construction, fundamental relationship between algebra and geometry, applications of geometry, geometry transformations and projective geometry, and convexity.

MME 522. Applications of Calculus

(2 credits)

There are three major goals for this course: to establish the underlying principles of calculus, to reinforce students' calculus skills through investigation of applications involving those skills, and to give students the opportunity to develop projects and laboratory assignments for use by first-year calculus students. The course will focus heavily on the use of technology to solve problems involving applications of calculus concepts. In addition, MME students will be expected to master the mathematical rigor of these calculus concepts so that they will be better prepared to develop their own projects and laboratory assignments. For example, if an MME student chose to develop a lab on convergence of sequence, he/she would be expected to understand the rigorous definition of convergence and how to apply it to gain sufficient and/or necessary conditions for convergence. The process of developing these first-year calculus assignments will enable the MME students to increase their own mathematical understanding of concepts while learning to handle mathematical and computer issues which will be encountered by their own calculus students. Their understanding of the concepts and applications of calculus will be further reinforced through computer laboratory assignments and group projects. Applications might include exponential decay of drugs in the body, optimal crankshaft design, population growth, or development of cruise control systems. (Prerequisite: MME 532)

MME 523. Analysis with Applications

(2 credits)

This course introduces students to mathematical analysis and its use in modeling. It will emphasize topics of calculus (including multidimensional) in a rigorous way. These topics will be motivated by their usefulness for understanding concepts of the calculus and for facilitating the solutions of engineering and science problems. Projects involving applications and appropriate use of technology will be an essential part of the course. Topics covered may include dynamical systems and differential equations; growth and decay; equilibrium; probabilistic dynamics; optimal decisions and reward; applying, building and validating models; functions on n-vectors; properties of functions; parametric equations; series; applications such as pendulum problems; electromagnetism; vibrations; electronics; transportation; gravitational fields; and heat loss. (Prerequisite: MME 532)

MME/SEME 524-25. Probability, Statistics and Data Analysis I, II

(4 credits)

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills:

- Probability models-mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena.
- Data analysis-the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized.
- Statistical inference and modeling-the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data.
- Design of experiments and sampling studies – the proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

MME 526-27. Linear Models I, II

(4 credits)

This two-course sequence imparts computational skills, particularly those involving matrices, to deepen understanding of mathematical structure and methods of proof; it also includes discussion on a variety of applications of the material developed, including linear optimization. Topics in this sequence may include systems of linear equations, vector spaces, linear independence, bases, linear transformations, determinants, eigenvalues and eigenvectors, systems of linear inequalities, linear programming problems, basic solutions, duality and game theory. Applications may include economic models, computer graphics, least squares approximation, systems of differential equations, graphs and networks, and Markov processes. (Prerequisite: MME 532)

MME 528. Mathematical Modeling and Problem Solving

(2 credits)

This course introduces students to the process of developing mathematical models as a means for solving real problems. The course will encompass several different modeling situations that utilize a variety of mathematical topics. The mathematical fundamentals of these topics will be discussed, but with continued reference to their use in finding

Return to Table of Contents

the solutions to problems. Problems to be covered include balance in small group behavior, traffic flow, air pollution flow, group decision making, transportation, assignment, project planning and the critical path method, genetics, inventory control and queueing. (Prerequisite: MME 532)

MME 529. Numbers, Polynomials and Algebraic Structures
(2 credits)
This course enables secondary mathematics teachers to see how commonly taught topics such as number systems and polynomials fit into the broader context of algebra. The course will begin with treatment of arithmetic, working through Euclid's algorithm and its applications, the fundamental theorem of arithmetic and its applications, multiplicative functions, the Chinese remainder theorem and the arithmetic of Z/n. This information will be carried over to polynomials in one variable over the rational and real numbers, culminating in the construction of root fields for polynomials via quotients of polynomial rings. Arithmetic in the Gaussian integers and the integers in various other quadratic fields (especially the field of cube roots of unity) will be explored through applications such as the generation of Pythagorean triples and solutions to other Diophantine equations (like finding integer-sided triangles with a 60 degree angle). The course will then explore cyclotomy, and the arithmetic in rings of cyclotomic integers. This will culminate in Gauss's construction of the regular 5-gon and 17-gon and the impossibility of constructing a 9-gon or trisecting a 60-degree angle. Finally, solutions of cubics and quartics by radicals will be studied. All topics will be based on the analysis of explicit calculations with (generalized) numbers. The proposed curriculum covers topics that are part of the folklore for high school mathematics (the impossibility of certain ruler and compass constructions), but that many teachers know only as facts. There are also many applications of the ideas that will allow the teachers to use results and ideas from abstract algebra to construct for their students problems that have manageable solutions.

MME 531. Discrete Mathematics
(3 credits)
This course deals with concepts and methods which emphasize the discrete nature in many problems and structures. The rapid growth of this branch of mathematics has been inspired by its wide range of applicability to diverse fields such as computer science, management, and biology. The essential ingredients of the course are:

Combinatorics -The Art of Counting. Topics include basic counting principles and methods such as recurrence relations, generating functions, the inclusion-exclusion principle and the pigeon-hole principle. Applications may include block designs, latin squares, finite projective planes, coding theory, optimization and algorithmic analysis.

Graph Theory. This includes direct graphs and networks. Among the parameters to be examined are traversibility, connectivity, planarity, duality and colorability.

MME 532. Differential Equations
(2 credits)
This course would have concepts and techniques for both Ordinary and Partial Differential Equations. Topics from ordinary differential equations include existence and uniqueness for first order, single variable problems as well as separation of variables and linear methods for first order problems. Second order, linear equations would be solved for both the homogeneous and non homogeneous cases. The phenomena of beats and resonance would be analyzed. The Laplace Transform would be introduced for appropriate second order nonhomogeneous problems. Partial Differential Equations would focus on boundary value problems arising from the Heat and Wave equations in one variable. Fourier Series expansions would be used to satisfy initial conditions and the concepts of orthogonality and convergence addressed.

MME 592/SEME 602. Project Preparation (Part of a 3-course sequence with MME 594 and MME 596)
(2 credits) (ISG)
Students will research and develop a mathematical topic or pedagogical technique. The project will typically lead to classroom implementation; however, a project involving mathematical research at an appropriate level of rigor will also be acceptable. Preparation will be completed in conjunction with at least one faculty member from the Mathematical Sciences Department and will include exhaustive research on the proposed topic. The course will result in a detailed proposal that will be presented to the MME Project Committee for approval; continuation with the project is contingent upon this approval.

MME 594/SEME 604. Project Implementation
(2 credits) (ISG)
Students will implement and carry out the project developed during the project preparation course. Periodic contact and/or observations will be made by the project advisor (see MME 592 Project Preparation) in order to provide feedback and to ensure completion of the proposed task. Data for the purpose of evaluation will be collected by the students throughout the term, when appropriate. If the project includes classroom implementation, the experiment will last for the duration of a semester.

MME 596/SEME 606. Project Analysis and Report
(2 credits) (ISG)
Students will complete a detailed statistical analysis of any data collected during the project implementation using techniques from MME 524-525 Probability, Statistics, and Data Analysis. The final report will be a comprehensive review of the relevant literature, project description, project implementation, any statisical results and conclusions. Project reports will be subject to approval by the MME Project committee and all students will be required to present their project to the mathematical sciences faculty. Course completion is contingent upon approval of the report and satisfactory completion of the presentation.

Mechanical Engineering

www.me.wpi.edu

Faculty

J. Yagoobi, George I. Alden Professor and Department Head; Ph.D., University of Illinois at Champaign-Urbana, 1984. Enhancement of heat transfer in macro, micro, and nano-scales, liquid vapor phase change, electrohydrodynamics, impinging jets, drying

I. Bar-On, Professor; Ph.D., Hebrew University of Jerusalem, 1984. Clean energy, economic impact of alternative energy systems, fuel cell technology, cost modeling, fatigue and fracture of ceramics, metals and composites

M. Bhatia, Assistant Teaching Professor, Ph.D., Arizona State University, 2014. Understanding the effect of 1D, 2D and 3D defects on structure-property relationships in advanced materials such as magnesium and titanium alloys related to the aerospace, automotive and nuclear industries at different length scales

C. A. Brown, Professor, Director Surface Metrology and Sports Engineering Laboratories; Ph.D., University of Vermont, 1983. Surface metrology, manufacturing, multi-scale geometric analyses, axiomatic design, sports engineering, and manufacturing processes

D. Cote, Assistant Professor; Ph.D., Worcester Polytechnic Institute, 2014. Computational thermodynamics, kinetics, and solidification; solid state additive manufacturing cold spray processing; powder metallurgy; microstructural analysis and modeling; through-process modeling

R. Daniello, Assistant Teaching Professor, Ph.D., University of Massachusetts, Amherst, 2013. Experimental studies of fluid behavior, microfluidics, superhydrophobic surfaces, wetting behavior and topography

C. Demetry, Professor; Ph.D., Massachusetts Institute of Technology, 1993. Pedagogical research and educational development, materials science and engineering education, educational technology, outcomes of K-12 engineering outreach, mentoring of women and girls in science and engineering

M. F. Dimentberg, Professor; Ph.D., Moscow Institute of Power Engineering, 1963. Applied mechanics, random vibrations, nonlinear dynamics, rotordynamics, mechanical signature analysis, stochastic mechanics

G. Fischer, Professor, Ph.D., Johns Hopkins University, 2008. Medical robotics, computer assisted surgery, robot control, automation, sensors and actuators

M. S. Fofana, Associate Professor, Ph.D., University of Waterloo, Waterloo, Canada, 1993. Nonlinear delay dynamical systems, stochastic bifurcations, regenerative chatter, numerically controlled CAD/CAM machining, vehicle ambulance reliability design and technology, systems engineering analysis, reduction of treatment delays in kidney dialysis, medical and public health engineering, emergency and disaster response robots

C. Furlong, Professor and Director, Center for Holographic Studies and Laser micro-mechaTronics; Ph.D., WPI, 1999. MEMS and MOEMS, micro- /nano-technology & -fabrication, mechatronics, laser metrology & applications, holographic and ultrasonic imaging and NDT, computer modeling of dynamic systems, acoustics.

A. Gnanaskandan, Assistant Professor, Ph.D., University of Minnesota, 2015 CFD, Multiscale modeling, Multiphase flows, Cavitation, Biomedical Acoustics, High-performance parallel computing, Algorithm development

S. I. Guceri, Professor, Ph.D., North Carolina State University, 1976. Rapid fabrication, rapid prototyping, layered manufacturing, additive manufacturing, laser manufacturing, bio-fabrication

Z. Hou, Professor; Ph.D., California Institute of Technology, 1990. Vibration and control, structural dynamics, structural health monitoring, smart materials and adaptive structures, stochastic mechanics, solid mechanics, finite elements, earthquake engineering

D. A. Lados, Milton Prince Higgins II Distinguished Professor of Mechanical Engineering; Director, Integrative Materials Design Center (iMdc); Ph.D., Worcester Polytechnic Institute, 2004. Fatigue, fatigue crack growth, thermo-mechanical fatigue, creep, and fracture of metallic and composite materials – evaluation, advanced material/failure characterization, life predictions, computational modeling and ICME, materials/process/component design and optimization for aerospace, automotive, marine, and military applications; advanced manufacturing – additive manufacturing, metal matrix nano–composites, friction stir welding, cold spray technology, powder metallurgy; residual stress; plasticity; fracture mechanics

F. C. Levey, Associate Teaching Professor; Ph.D., University of the Witwatersrand, 2001. Phase diagrams, phase transformations, shape memory, ferro-alloy casting

Z. Li, Assistant Professor; Ph.D., University of California at Santa Cruz, 2014. Human-robot interaction, perception-actino coordination of cyber-human system, shared autonomous medical robots for nursing, rehabilitation and surgery

J. Liang, Professor; Ph.D., Brown University 2004. Nanofabrication through nonlithographic approaches, additive manufacturing, material processing, resource recycling, and material characterization

Y. Liu, Associate Professor; Ph.D., University of Maryland, 2011. Fiber optical tweezers, silicon nanophotonics and nanomechanics, fiber optic sensors, medical robotics, cell mechanics

M. M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute, 1990. Physical metallurgy, specifically developing new alloys for improved performance. Materials processing, particularly solidification of metals. The application of thermodynamics, kinetics, and the concepts of heat and mass transfer to modeling processes in materials science and engineering. Metal-matrix nanocomposites.

Return to Table of Contents

B. Mishra, Kenneth G. Merriam Professor; Director, Metal Processing Institute; Ph.D., University of Minnesota, 1986. Physico-chemical processing of materials, corrosion science and engineering, resource recovery & recycling, critical materials extraction, iron and steelmaking, alloy development, thin film coatings and surface engineering

S. P. Narra, Assistant Professor; Ph.D., Carnegie Mellon University, 2017. Additive manufacturing, process-structure-property relationships, location-specific control of properties, process control and modeling, combining physics-based understanding with data analytics

C. D. Onal, Associate Professor; Ph.D., Carnegie Mellon University, 2009. Postdoc, Massachusetts Institute of Technology, 2009-2012. Unconventional approaches to robotics, actuation, sensing, and control of devices made of soft materials or mechanisms, printable robotics, human augmentation

B. Panchapakesan, Professor; Ph.D., University of Maryland, 2001. Nanomanufacturing, light-driven actuators, micro/nano-opto-mechanical systems, nanotube liquid crystals, 2-D nano-materials, and micro and nanotechnology approaches to capture circulating tumor cells

A. Powell, Associate Professor; Ph.D., Massachusetts Institute of Technology, 1997. Clean production of materials particularly those used in clean energy, electrochemistry, extractive metallurgy, multiscale modeling of materials process fundamentals, industrial ecology

P. Radhakrishnan, Associate Teaching Professor; Ph.D., The University of Texas at Austin, 2014. Automated design and manufacturing; entertainment and medical engineering; optimization, machine learning and software development; kinematics, dynamics and design education

P. M. Rao, Associate Professor; Ph.D., Stanford University, 2013. Solar energy materials, photovoltaic and photoelectro-chemical materials, scalable synthesis of nanostructured thin film materials

A. C. Sabuncu, Assistant Teaching Professor; PhD, Old Dominion University, 2011. Thermo-fluid science and engineering with a focus on micro&nano scale systems. In addition, expertise on dielectric spectroscopy of biological materials.

B. J. Savilonis, Professor; Ph.D., State University of New York at Buffalo, 1976. Thermofluids, biofluids and biomechanics, energy

C. Scarpino, Instructor/Lecturer; MSc. Worcester Polytechnic Institute, 1994. Teaching faculty for engineering experimentation. Geothermal Heat Pumps. Medical devices for hearing research. Computational modeling of heat transfer in thin films

S. S. Shivkumar, Professor; Ph.D., Stevens Institute of Technology 1987. Plastics, materials science and engineering, biomaterials, food engineering

R. D. Sisson, Jr., George F. Fuller Professor; Director, Manufacturing and Materials Engineering; Ph.D., Purdue University, 1975. Materials process modeling and control, manufacturing engineering, corrosion, environmental effects on metals and ceramics

W. Soboyejo, Professor, Provost ad Interim; Ph.D., Cambridge University, 1988. Biomaterials, use of nanoparticles for detection and treatment of disease, mechanical properties of materials, use of materials science to promote global development.

J. Stabile, Instructor, MSME, University of Arizona; MEEE, University of Colorado. High efficiency small speaker systems for personal audio. This would include magnetic motor design, linear and rotary actuators, high bandwidth structural design, force balanced transducer design, acoustic structural interaction modeling with finite element analysis, and planar acoustic arrays. 3D additive creation of planar electromagnetic actuators

J. M. Sullivan, Jr., Professor, Associate Department Head; D.E., Dartmouth College, 1986. Development of graphics tools and mesh generation, numerical analysis of partial differential equations, medical image visualization and analysis software development

Y. Wang, Professor; Ph.D., University of Windsor, 2008. Battery materials, structure, manufacturing, design, recycling and safety, electrochemistry based technologies, electrolysis, recycling and sustainability, fundamental electrochemistry, commercialization of technologies

S. Wodin-Schwartz, Assistant Teaching Professor; Ph.D., University of California at Berkeley, 2013. MEMS sensor design and fabrication, undergraduate engineering education, active learning and experiential education content development and research, product design.

X. Zeng, Assistant Professor; Ph.D., The Ohio State University, 2016. Automotive Dynamic Systems and mobility cyber-physical system modeling, analysis, estimation, optimization, and control

Y. Zheng, Assistant Professor; Ph.D., University of Michigan, 2016. Advanced and biomedical manufacturing, medical device design, tissue mechanics, biomedical machining process and modeling, catheter-based surgical devices, medical simulation, vascular ultrasound imaging, abrasive machining processes for biomedical and ceramic materials.

Y. Zhong, Associate Professor; Ph.D., Penn State University, 2005. Integrated Computational Materials Engineering (ICME), computational thermodynamics, ab initio, alloys and ceramics

Emeritus

D. Apelian, Professor Emeritus
R. Biederman, Professor Emeritus
J. M. Boyd, Professor Emeritus
A. H. Hoffman, Professor Emeritus
J. A. Mayer, Jr., Professor Emeritus
R. L. Norton, Professor Emeritus
R. J. Pryputniewicz, Professor Emeritus

Areas of Study

The graduate curriculum is divided into five distinct areas of study:

- Fluids Engineering
- Dynamics and Controls
- Structures and Materials
- Design and Manufacturing
- Biomechanical Engineering

These areas support the research interests of the mechanical engineering faculty, which are described under Areas of Research. Graduate courses introduce students to fundamentals of mechanical engineering while simultaneously providing the background necessary to become involved with the ongoing research of the mechanical engineering faculty.

Students also receive credit for special topics under ME 593 and ME 693, and independent study under ISP. Faculty members often experiment with new courses under the special topics designation, although no course may be offered more than twice in this manner. Except for certain 4000-level courses permitted in the B.S./ Master's program, no undergraduate courses may be counted toward graduate credit.

Programs of Study

The Mechanical Engineering Program offers the following graduate degree options:

- Master of Science (M.S.)
- Combined B.S./M.S.
- Doctor of Philosophy (Ph.D.)
- Graduate Certificate Program: Mechanical Engineering for Technical Leaders

Admission Requirements

For the M.S. program, applicants should have a B.S. in mechanical engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.).

The standards are the same for admission into the thesis and non-thesis options of the M.S. program. At the time of application to the master's program, the student must specify his/her option (thesis or non-thesis) of choice.

For the Ph.D., a bachelor's or master's degree in mechanical engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.) is required.

The Mechanical Engineering Department reserves its financial aid for graduate students in the Ph.D. program or in the thesis option of the M.S. program.

Degree Requirements

M.S. Program

When applying to the master of science program, students must specify their intention to pursue either the thesis or non-thesis M.S. option. Both the thesis and non-thesis options require the completion of 30 graduate credit hours. Students in the thesis option must complete 12 credits of thesis research (ME 599), whereas students in the non-thesis option may complete up to 9 credits of directed research (ME 598). The result of the research credits (ME 599) in the thesis option must be a completed master's thesis. The number of directed research credits (ME 598) completed in the non-thesis option can range from 0 to 9.

In the thesis option, the distribution of credits is as follows:

- 9 graduate credits in mechanical engineering
- 12 credits of thesis research (ME 599)
- ME 5000 (2 credits) or 3 credits of graduate-level mathematics
- 6 graduate credits of electives within or outside of mechanical engineering

In the non-thesis option, the distribution of credits is as follows:

- 18 graduate credits in mechanical engineering (includes a maximum of 9 credits of directed research—ME 598)
- 3 graduate credits in mathematics
- 9 graduate credits of electives within or outside of mechanical engineering

In either option, all full-time students are required to register for the graduate seminar (ME591) every semester.

Academic Advising

Upon admission to the M.S. program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. This plan must be made before the first registration. Prior to registering for additional credits, the student must specify an academic advisor with whom the remaining course of study is arranged. The plan must be approved by the mechanical engineering graduate committee.

For students in the thesis option, the academic advisor is the thesis advisor. Prior to completing more than 18 credits, every student in the thesis option must form a thesis committee that consists of the thesis advisor and at least two other mechanical engineering faculty members from WPI with knowledge of the thesis topic.

The schedule of academic advising is as follows:

- Temporary advisor—meets with student prior to first registration to plan the first 9 credits of study.
- Academic advisor—selected by student prior to registering for more than 9 credits. For thesis option students, the academic advisor is the thesis advisor.
- Plan of Study—arranged with academic advisor prior to registering for more than 9 credits.
- Thesis committee (thesis option only) —formed prior to registering for more than 18 credits. Consists of the thesis advisor and at least two other mechanical engineering faculty members from WPI.

This schedule ensures that students are well advised throughout the program, and that students in the thesis option are actively engaged in their research at the early stages of their programs.

Thesis Defense

Each student in the thesis option must defend his/her research during an oral defense, which is administered by an examining committee that consists of the thesis committee and a representative of the mechanical engineering graduate committee who is not on the thesis committee. The defense is open to public participation and consists of a 30-minute presentation by the student followed by a 30-minute open discussion. At least one week prior to the defense each member of the examining committee must receive a copy of the thesis. One additional copy must be made available for members of the WPI community wishing to read the thesis prior to the defense. Public notification of the defense must be given by the mechanical engineering graduate secretary. The examining committee will determine the acceptability of the student's thesis and oral performance. The thesis advisor will determine the student's grade.

Changing M.S. Options

Students in the non-thesis M.S. option may switch into the thesis option at any time by notifying the mechanical engineering graduate committee of the change, provided that they have identified a thesis advisor, formed a thesis committee, and have worked out a Plan of Study with their thesis advisor. Subject to the thesis advisor's approval, directed research credits (ME 598) earned in the non-thesis option may be transferred to thesis research credits (ME 599) in the thesis option.

Any student in the thesis option M.S. program may request a switch into the non-thesis option by submitting the request in writing to the mechanical engineering graduate committee. Before acting on such a request, the graduate committee will require and seriously consider written input from the student's thesis advisor. Departmental financial aid given to the thesis-option students who are permitted to switch to the non-thesis option will automatically be withdrawn. Subject to the approval of the mechanical engineering graduate committee, a maximum of 9 credits of thesis research (ME 599) earned by a student in the thesis option may be transferred to directed research credit (ME 598) in the non-thesis option.

The Combined Bachelor's/ Master's Program

The Mechanical Engineering Department offers a B.S./Master's program for currently enrolled WPI undergraduates. Students in the B.S./Master's program may choose either the thesis or non-thesis M.S. option. The department's rules for these programs vary somewhat from the Institute's rules. For students in the B.S./Master's program, a minimum of six credits and a maximum of twelve credits may be counted toward both the undergraduate and graduate degrees. At least six must be from graduate course credits (including graduate-level independent study and special topics courses), and none may be from courses lower than the 4000-level. No extra work is required in the 4000-level courses. A grade of B or better is required for any course to be counted toward both degrees.

Students can apply to the BS/MS program by submitting an MS application to WPI Graduate Admissions and selecting the BS/MS option.

The application for the B.S./Master's program must include a list of courses that the applicant proposes to count toward both his/her undergraduate and graduate degrees. In most cases, the list consists of courses that the applicant will take in the senior year.

Applications will not be considered if they are submitted prior to the second half of the applicant's junior year. Ideally, applications (including recommendations) should be completed by the early part of the last term (usually D-term) of the junior year.

Acceptance into the B.S./Master's program means that the candidate is qualified for graduate school, and signifies approval of the courses listed for credit toward both the undergraduate and graduate degrees. However, admission is contingent upon the completion of six graduate credits (from the submitted list) with grades of B or better in each. If grades of C or lower are obtained in any other listed courses, then they are not counted toward the graduate degree, but the applicant is still admitted to the program.

Students in the B.S./Master's program who choose the thesis M.S. option are encouraged to pick a thesis area of research that is closely related to the subject of their major qualifying project. Those students in the B.S./Master's program who complete their B.S. degrees in May and choose the thesis option are encouraged to begin their thesis research during the summer immediately following graduation.

A detailed written description of the B.S./Master's program in mechanical engineering can be obtained from the mechanical engineering graduate secretary.

Ph.D. Program

The course of study leading to the Ph.D. degree in mechanical engineering requires the completion of 90 graduate-level credits beyond the bachelor's degree, or 60 graduate-level credits beyond the master's degree. For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

Coursework:	
Courses in M.E. (incl. Special Topics and ISP)	15 credits
Courses in or outside of M.E.	15 credits
Dissertation Research (ME 699)	30 credits
Other:	
Additional coursework Additional Dissertation Research (ME 699) Supplemental Research (ME 598, ME 698)	30 credits
TOTAL	90 credits

For students proceeding from master's to Ph.D. degree, the 60 credits should be distributed as follows:

Coursework: (incl. Special Topics and ISP)	12 credits
Dissertation Research (ME 699)	30 credits
Other:	
Additional coursework Additional Dissertation Research (ME 699) Supplemental Research (ME 598, ME 698)	18 credits
TOTAL	60 credits

In either case, the result of the dissertation research must be a completed doctoral dissertation. Only after admission to candidacy may a student receive credit toward dissertation research under ME 699. Prior to admission to candidacy, a student may receive up to 18 credits of predissertation research under ME 698. All full-time students are required to register for the graduate seminar (ME 591)every semester.

Academic Advising

Upon admission to the Doctoral Program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. This plan should be arranged before the first day of registration.

Prior to registering for any additional credits, the student must identify a permanent dissertation advisor who assumes the role of academic advisor and with whom a suitable dissertation topic and the remaining Plan of Study are arranged. Prior to completing 18 credits, the student must form a dissertation committee that consists of the dissertation advisor, at least two other mechanical engineering faculty members, and at least one member from outside the department. These committee members should be selected because of their abilities to assist in the student's dissertation research.

The schedule of advising is as follows:

- Temporary advisor—meets with student prior to first registration to plan first 9 credits of study.
- Dissertation advisor—selected by student prior to registering for more than 9 credits.
- Program of study—arranged with Dissertation advisor prior to registering for more than 9 credits.
- Dissertation committee—formed by student prior to registering for more than 18 credits. Consists of dissertation advisor, at least two M.E. faculty, and at least one outside member.

This schedule ensures that students are well advised and actively engaged in their research at the early stages of their programs.

Admission to Candidacy

Admission to candidacy will be granted when the student has satisfactorily passed a written exam intended to measure fundamental ability in three of the following nine areas: fluid mechanics, heat transfer, dynamics, controls, structures, materials, design, manufacturing, and biomechanical engineering. The three areas are selected by the student, with the approval of the PhD advisor. The exam questions will be at the first-year graduate level. The Ph.D. candidacy exam is given in September and January. For students who enter the program with a master's degree in mechanical engineering, the exam must be taken for the first time after one semester of study (i.e.: in January if they began in the fall; and in September if they began in the spring.). For all other students, the exam must be taken for the first time after two semesters of study (i.e. in September if they began in the fall, and in January if they began in the spring.) Any student who does not pass the exam in all three areas chosen must retake the exam (in the areas not passed) one semester later (i.e.: in September if they did not pass in January; and in January if they did not pass in September). Students are not allowed to take the exam more than twice. The details of the examination procedure can be obtained from the mechanical engineering graduate committee.

Dissertation Proposal

Each student must prepare a brief written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to date. An important part of the written and oral proposal should be a description of the potential applications and societal impact of the research. The proposal must be made within 18 months of admission to candidacy. Both the written and oral proposals are presented to the dissertation committee and a representative from the mechanical engineering graduate committee. The prepared portion of the oral presentation should not exceed 30 minutes, and up to 90 minutes should be allowed for discussion. If the dissertation committee and the graduate committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, then the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 45 minutes allowed for discussion. Students can continue their research only if the proposal is approved.

Dissertation Defense

Each doctoral candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the dissertation committee and a representative of the mechanical engineering graduate committee who is not on the dissertation committee. In addition to providing a summary of the relevant literature and a description of the techniques employed, technical issues addressed, and results obtained, both the dissertation and the oral defense should include a description of the potential applications and societal impact of the research. The defense is open to public participation and consists of a 45-minute presentation followed by a 45-minute open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the mechanical engineering graduate secretary. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

Graduate Certificate Program: Mechanical Engineering for Technical Leaders (METL)

Companies recognize that employees who pursue graduate education oftentimes become the future technical leaders within their organization. As leaders, it is important that they possess not only the engineering skills to understand technical problems that require novel and innovative solutions, but also the business and managerial skills to harness the resources (human and capital) to implement these solutions. This certificate combines graduate mechanical engineering coursework to enhance their technical expertise along with leadership and management coursework to empower them to lead technical teams, make sound business decisions and bring their projects to successful conclusion.

Requirements:

9 credits in graduate level Mechanical Engineering courses*

9 credits in graduate level Business courses**

* Note: Students may petition the Mechanical Engineering Graduate Committee to count up to 4 credits in MTE graduate courses. Petitions must be approved before students register for these MTE credits.

** Note: Students may use CE 580 (Advanced Project Management) toward this requirement.

Admission to the Certificate Program:
Students wishing to enroll in the METL Certificate program must submit a full M.S. graduate application.

Return to Table of Contents

Successful Completion of the METL Certificate Program:
Successful completion of the METL certificate program requires:

- completion of the 18 credits distributed as described above; and
- an overall GPA of at least 3.0.

Subsequent Admission into the M.S. program in Mechanical Engineering:
Students wishing to continue their studies in the M.S. program in Mechanical Engineering will be admitted upon request provided that they have:

- completed the METL certificate program; and
- earned a GPA of at least 3.0 within the 9 credits of M.E. courses (including any AE and MTE credits permitted by petition).

For B.S. students who continue on to the M.S. program in Mechanical Engineering, any MTE credits that have been used to satisfy the METL certificate requirements will be counted as M.E. credits toward the M.S. degree. Current graduate students in the ME program are also allowed to obtain this METL certificate. All students who wish to apply to the METL certificate program should submit a formal application to WPI Graduate Admissions.

Areas of Research

The faculty of the Mechanical Engineering Department currently pursue research under the following areas:

- Biomechanical Engineering and Healthcare
- Dynamics, Controls and Robotics
- Energy Science and Engineering
- Materials and Manufacturing
- Mechanics and Design
- Nano and Micro Engineering

Please consult the Mechanical Engineering Department website for a current list of the faculty pursuing research under each of these areas.

Mechanical Engineering Laboratories and Centers

The Mechanical Engineering Program provides a multidisciplinary research and education environment. The facilities are housed in Higgins Laboratories and Washburn Shops. For the laboratories and centers of the other programs within the Mechanical Engineering Department (Aerospace Engineering, Manufacturing Engineering, Materials Process Engineering, and Materials Science and Engineering), please see their corresponding sections in this catalog.

Teaching and Project Laboratories

Design Studio and Computer Classroom

The Higgins Design Studio (HL 234) and the Computer Classroom (HL 230) are both part of the Keck Design Center, and are managed by WPI's Information Technology Services Division. The labs are used for lectures and laboratories in a variety of mechanical design and manufacturing courses, and are also available to students for general-purpose computational work on projects and coursework. The 1600 sq. ft. Higgins Design Studio contains twenty one (21) high-end workstations running software for mechanical design including parametric solid modeling (PTC/Creo, Solidworks, NX, Ideas), structural, thermal, fluid and dynamic analysis (ANSYS, Abaqus, Nastran, Patran, Fluent, Comsol) and general purpose applications (Tecplot, sigmaplot, Mathematica, MatLab, Maple). Auxiliary equipment includes two laser printers and 2 E-size color printer/plotter. The 1575 sq. ft. Computer Classroom (HL 230) contains more than forty (40) workstations, A/V equipment including dual high-resolution projection systems, and a high-speed laser printer. Locally installed software includes Solidworks, AutoCAD, Matlab, Maple, Mathcad, TK Solver, Thermal Analysis software and VisualStudio. Net. The workstations in the Design Studio and Computer Classroom have access to all software available on the WPI campus network, and allow for design collaboration and exchange of design models to manufacturing facilities. Courses served: ES 1020, ES 1310, ME 3310, ME 3311, ME 3320, ME 4320 and many out-of- department courses.

Experimentation Laboratory

The Experimentation Laboratory (HL 031) provides the Mechanical Engineering Department with a modern laboratory for the state-of-art Engineering Experimentation ME 3901 course, required for ME students to satisfy their experimentation requirement. The course provides students with valuable hands-on knowledge and directly addresses all ABET experimentation and related requirements. The 1300 sq. ft. laboratory houses 15 workstations containing Labview-based data acquisition hardware and software. Each workstation is configured for two students working in pairs. A host of standard sensors and transducers (thermocouples, thermistors, RTDs, strain gages, pressure transducers, accelerometers, etc.) complement each workstation bench. The laboratory also contains standard test equipment (DVM, soldering equipment, hand tools, calipers, and micrometers) as well as hardware apparatus such as pressure tanks, orifices, heat exchangers, pressurized air, power, and internet, etc. This laboratory is also used for ES 3011 Engineering Controls I, ME 4322 Modeling and Analysis of Mechatronics, a graduate course on Dynamic Signal Analysis, and Major Qualifying Projects (MQPs) related to engineering experimentation.

Major Qualifying Projects (MQP) Laboratory

The MQP Laboratory (HL 045) is a 450 sq. ft. space for students to assemble and work on their MQPs. The laboratory lies between the Engineering Experimentation Laboratory, giving access to state-of-art electronic sensors and measurement equipment, and the Higgins Machine Shop, providing lathes, drill presses, milling machines and CNC equipment. The MQP laboratory is equipped with air, water, drains, and hand-tools for fabrication work. Individualized storage exists for capstone design works in progress.

Project Laboratories

The other project laboratory spaces in Higgins Laboratories include HL 005, 006, 017, and 019. HL 005 (1600 sq. ft.) is used primarily to conduct of capstone design projects requiring a large work and assembly area. It also provides space to one of WPI's US First Robotics teams and supports the Robotics Resource Center (HL 009), as well as being the home of WPI's CollabLab, which is a student organization that promotes "maker" culture and collaboration at WPI. The SAE Project Lab (HL 006, 300 sq. ft.) houses the SAE Formula Race Car and other SAE projects. HL 017 and 019 (each approximately 100 sq. ft.) provide further space and resources for conducting course projects and MQP projects.

Manufacturing Facilities

3D Print Laboratory

Rapid Prototyping (RP) technologies, including 3D printing, use a computer-driven, additive process to print solid three-dimensional models one layer at a time almost directly from a computer-aided design (CAD) program. The 3D Print Laboratory (HL 232) houses several executive level RP machines managed by Academic & Research Computing (ARC) Center staff available for students, faculty, and staff across campus. The Dimension SST 1200es prints exclusively with ABS plastic, and the Objet 260 Connex is capable of using a variety of resins that can produce up to 14 different material properties within one part, with over 60 material options available. Submissions to the machines are accepted for any on campus projects (MQP, IQP, course project, graduate research, etc.) that have been approved by an advisor or faculty member, for the production of parts that cannot be easily purchased or created using other on campus resources. Instructions for access can be found at https://www.wpi.edu/research/resources/academic-research-computing/3d-printing, and the staff can be contacted at rapidprototyping@wpi.edu

CNC Teaching Laboratory

The CNC teaching laboratory is located in the Washburn Shops Room 107 and covers 3,140 sq. ft. The CNC machine tools housed within this lab are used for a wide range of student projects including MQPs, and also in ME 1800, ME 3820, and other courses. The laboratory is equipped with one Universal Laser Systems VLS60 Laser Cutter, one Makerbot Replicator 2X, 3 Haas MiniMills and 2 Haas SL10s, 3 band saws, two drill presses, a sheet metal shear and bending break as well as assorted hand tools. Attached to each of the MiniMills and SL10s are computer workstations equipped design and programming software. In addition to the computers located at each of the CNC machine tools, the facility has two computer classrooms, one in Washburn 107 and the other in Washburn 105, which can be configured to contain between 8 and 12 computer workstations. These workstations have access to the design software packages supported on campus as well as our training materials and several Computer Aided Manufacturing (CAM) software packages including Esprit, MasterCam, and SurfCam. The facilities are run by an operations manager and lab machinists who are assisted by undergraduate peer learning assistants (PLAs).

Higgins Machine Shop

The 600 sq. ft. machine shop in Higgins Labs is located in HL 004, and contains 2 CNC Machine tools (a Haas Tool Room Mill and a Haas Tool Room Lathe), as well as a surface grinder, 2 DoAll Mills and a DoAll engine lathe as well as a drill press, 2 band saws and assorted hand tools. A machinist manages and supports the machine shop and project activities with the assistance of undergraduate PLAs.

MEMS Fabrication Laboratory

The MEMS Fabrication Laboratory (HL 106) is a Class 100 cleanroom facility with approximately 500 square feet of floor space, including the gowning area. It is equipped with instrumentation to support photolithography, thermal deposition and oxidation, wet chemistry, metrology, and wafer bonding. Metrology capabilities for the devices that are fabricated, such as profilometry, SEM, AFM, and XRD are available through other ME Department laboratories, including the Materials Characterization Laboratory (see Materials Science and Engineering section of this catalog).

Research Laboratories

Automation and Interventional Medicine Laboratory

The Automation and Interventional Medicine Laboratory (AIM Lab) is located at 85 Prescott Street (Gateway Park). The primary focus of projects in the AIM Lab is medical robotics including: robotic surgery, image-guided surgery, MRI-compatible mechatronics, rehabilitation robotics, socially assistive robotics, and biofabrication. The lab contains 10 student workstations, equipment for mechanical and electrical design, construction, configuration, and testing of robots, control systems, and automated test fixtures, including state-of-the-art electronics testing and micro-electronics assembly equipment and supplies. An NDI Polaris optical tracker is available for motion capture. The lab houses MRI robot controllers developed in the AIM lab and custom control electronics for high precision control of piezoelectric motor drive waveforms and corresponding robotic system testbeds. A daVinci Research Kit (dVRK) surgical robot is also available in the lab which includes the Intuitive Surgical robot with custom open control systems. Additional access to a 3T Philips MRI scanner and affiliated personnel is available through collaboration with the nearby UMass Medical School. Collaboration with the Brigham and Women's Hospital provides a second clinical site. BWH has specially configured scanners for real-time image acquisition and scanner control readily implemented with the robot. The Advanced Multimodality Image Guided Operating (AMIGO) suite provides an ideal clinical validation environment. The research in the AIM Lab is directed by Prof. G. Fischer. Further information can be found at http://aimlab.wpi.edu/.

Medical and Manufacturing Innovation Laboratory

The Medical and Manufacturing Innovation Lab (MedMan) is located in HL 029, 037, and 039 on the main campus, as well as the Collaborative Lab of the PracticePoint at the Gateway Park. RESEARCH The MedMan goal is to advance engineering science and technology to enhance healthcare. Specifically, MedMan applies advanced

Return to Table of Contents

robotics, manufacturing, and design for safety, quality, efficiency, and economy in healthcare service and research. MedMan balances fundamental science and clinical applications, producing research articles and patents, scientists and entrepreneurs. PROJECTS Some representative projects are high-speed grinding inside human arteries to clear the blockage and treat cardiovascular diseases, high-speed machining of blood clot inside the human brain to treat stroke, a tele-ultrasound imaging system with intuitive user interfaces, robotic catheterization for neuro intervention, mechanical testing of blood clot, atherosclerotic plaque, and brain tissues, hydrodynamic polishing for 3D printed internal channels. COLLABORATION MedMan has been extensively collaborating with healthcare organizations and medical schools nationwide including Beth Israel Deaconess Medical Center, Mayo Clinic, VA Ann Arbor Healthcare System, Saint Vincent Hospital, University of Massachusetts Medical School, University of Michigan Medical School, and Massachusetts College of Pharmacy and Health Sciences. MedMan has also worked with medical device companies including Boston Scientific, Cardiovascular Systems Inc., Endovascular Engineering, and Calcium Solutions. The MedMan Lab is directed by Prof. Y. Zheng. Further information can be found at http://medman.wpi.edu/.

Metal Additive Manufacturing Lab

At metal additive manufacturing lab, we advance the state-of-the-art in additive manufacturing by working at the intersection of mechanical engineering, materials science, and manufacturing. We specifically use laser powder bed fusion, electron beam powder bed fusion, and wire arc additive manufacturing processes on structural materials such as titanium, nickel, aluminum-based alloys and steels. Our goal is to develop and utilize process-structure-property relations for different processes and materials to achieve desired microstructures and properties. Our lab has an SLM 125 laser powder bed fusion equipment that is suitable for parameter development using small quantities of powders which is especially advantageous for materials development activities. This machine is also equipped with in-situ monitoring capabilities such as melt pool monitoring and laser power monitoring. We also leverage collaborations with other universities, national labs, and companies for access to equipment and complementary skills to achieve our goals. The research in the metal additive manufacturing lab is directed by Prof. S.P. Narra. Further information can be found at https://sites.google.com/view/narrateam/home.

Multi-Scale Heat Transfer Laboratory

The Multi-Scale Heat Transfer (MHT) Laboratory is located in HL 248, and investigates the enhancement of heat transfer and mass transport in nano-, micro-, and macro-scales, with and without working fluid phase change (liquid/vapor), in the presence and absence of gravity utilizing various mechanisms of electrohydrodynamics (EHD). The MHT Laboratory also studies the augmentation of heat transfer with micro-scale phase change materials under various fluid flow configurations. MHT Laboratory features the following two-phase flow experimental apparatuses: EHD pump in micro scale for water droplet activation; multi-functional in-tube (internal forced convection) condensation and boiling in horizontal configuration using EHD polarization force; external condensation in horizontal configuration using EHD induction pumping; external condensation in vertical configuration using EHD polarization force; in-channel (internal forced convection) condensation in horizontal configuration using EHD induction pumping; two-phase loop with EHD induction pumping; and pool boiling for low and high pressure refrigerants using EHD polarization force. The MHT Laboratory also features several flexible pumps in various configurations and sizes. Supporting equipment include a large scale two-phase system (heat pipe loop), a unique high voltage, three-phase power supply, several high voltage (0-50kV) dc power supplies, a high-speed video system, micro-fiber optic temperature measurement device, high resolution infrared camera , thermistors, heat flux sensors, pressure transducers, flow meters, vacuum pumps, recirculating chillers, oscilloscope, multi-meters, and desktop computers. The research in the MHT Lab is directed by Prof. Prof. J. Yagoobi. Further information can be found at http://mht.wpi.edu/.

NanoEnergy Laboratory

The NanoEnergy Lab is located in Rooms 4916 and 4918, 50 Prescott St. (Gateway Park II), and targets the synthesis and study of nanomaterials for energy conversion applications, particularly for converting solar energy to electrical or chemical energy (photovoltaic and photoelectrochemical energy conversion). The goal is to use nanostructuring and scalable, economical synthesis methods to dramatically improve the energy conversion efficiency of earth-abundant, low-cost materials. Materials synthesis equipment in the NanoEnergy Lab includes vapor deposition (flat-flame burner and multi-zone tube furnace), hydrothermal synthesis reactors, solution deposition (fume hood, spincoater), and various furnaces for annealing materials. Light sources, integrating spheres, spectrometers, a potentiostat, electrochemical cells and chemical sensors are available for the characterization of optical, electronic, photovoltaic and photoelectrochemical properties and behavior of materials. The research in the NanoEnergy Lab is directed by Prof. P. Rao. Further information can be found at http://nanoenergy.wpi.edu/.

Optomechanics Laboratory

The WPI Optomechanics Lab is located in Rooms 4934 and 4938, 50 Prescott St. (Gateway Park II). The overarching goal is to develop tools based on coupling between optics and mechanics at the micro- and nanoscale, and applying these tools to tackle challenging problems at the intersection of various disciplines. The main research carried out includes fiber optical tweezers, silicon nanomechanics, silicon nanophotonics, optofluidics, and fiber optic sensors. The research in the Optomechanics Lab can find applications in cell mechanics, on-chip disease diagnosis, precision displacement/force measurements, and biomedical sensing. The lab has various facilities for optical and mechanical research at the micro/nanoscale, such as a tunable diode laser, pigtailed laser diodes, automatic fiber fusion splicers, fiber end polisher, and a large variety of photodetectors and power meters. There are various microscopes available for imaging and measurements, including one research-grade inverted fluorescence microscope for biological research and a long-working-distance microscope for nanophotonic and microfluidic research. The lab is specialized in home-made fiber optical tweezer systems, which enable non-contact nanoparticle manipulation and picoNewton force measurements. Piezo stages and a 6-GHz electronic spectrum analyzer enable nanometer displacement control and GHz-range dynamic signal measurements. The research in the Optomechanics Laboratory is directed by Prof. Y. Liu. Further information can be found at http://optomech.wpi.edu/.

Small Systems Laboratory

The Small Systems Laboratory (SSL) is located in HL 124, and is dedicated to the development of multi-functional materials, devices and systems at the macro-, micro-, meso- and nanoscales. Our work spans multiple areas bridging multiple disciplines and multiple length scales. Facilities at SSL include fabrication and characterization units for advanced materials, device processing and testing and biomaterials characterization. Specific ongoing research projects are in the area of novel nanocomposites, energy efficient materials and devices, stimuli responsive materials, photoconductive devices and biomedical nanotechnology. Research in the SSL is directed by Prof. B. Panchapakesan. Further information can be found at https://wp.wpi.edu/baloolab/.

Soft Robotics Laboratory

The Soft Robotics Laboratory is located in HL 127, and supports personnel and equipment required for the design, development, and control of next-generation soft, flexible, and semi-rigid robotic systems. Projects in the lab include studying and developing soft robotic snakes, octopus arms, origami-inspired hexapods, tentacles, flying robots, wearable haptic interfaces, human-robot interaction, and multi-robot systems. Equipment in the Soft Robotics lab includes devices for design, fabrication, experimentation, and analysis, including an Epilog Zing 24 CO2 laser cutter, a dual nozzle 3D printer, a motion capture area, various semi-rigidware packages for mechanical and electronic design, a full custom-made flexible circuit fabrication and assembly equipment suite, a large-workspace optical microscope, an elastomeric fabrication workbench, and various data acquisition and analysis systems. The lab currently supports research activities in elastomeric robotic systems, printed circuit and sensor manufacturing, origami-inspired foldable systems, assistive soft robotic monitoring, bio-inspired stereo vision, and prosthetic robotics. Research in the Soft Robotics Laboratory is directed by Prof. C. Onal. Further information can be found at http://softrobotics.wpi.edu/.

Surface Metrology Laboratory

WPI's Surface Metrology Lab is one of just a few academic labs in the world that focuses on measurement and analysis of surface topographies, or roughness. Through the generosity of the respective companies the lab has the use of an Olympus LEXT OLS4100 laser scanning confocal microscope, a Solarius SolarScan white light microscope and a Mahr-Federal MarSurf GD25 stylus profiler for measuring topographies, as well as Mountains Map (DigitalSurf), Modal Filter, and Sfrax, software for analysis. We study how topographies are influenced by processing and influence the performance of surfaces. One task it to find ways to discriminate surfaces that were processed differently, or that perform differently, based on topographic measurement and analysis. Another task is to find functional correlations between topographies and their processing or their performance. The lab has pioneered the development and application of several kinds of multi-scale analyses including geometric and fractal analyses for discrimination and correlation. The lab serves industry and collaborates with engineers and scientists from a variety of disciplines around the world. The lab is directed by Prof. C. Brown.

Research Centers

Center for Advanced Research in Drying

The Center for Advanced Research in Drying (CARD) is a National Science Foundation (NSF) Industry/University Cooperative Center (I/UCRC) devoted to research in drying of moist, porous materials such as food and other agricultural products, forestry products, chemical products, textiles, and biopharmaceuticals. CARD was founded by WPI as a lead institution, and the University of Illinois at Urbana-Champaign. Examples of the current CARD research areas include:

- Drying Processes/Systems Design and Simulation
- Optimizing Product Quality and Energy Consumption during Drying by Solving Multi-scale Transport Models
- Nano- and Micro-Technology in Drying Applications
- Innovative Concepts in Drying of Moist Porous Materials
- Moisture Management for Food Quality, Stability and Safety
- Phase Behavior of Biopolymers and Impact on Product Quality
- Machine Learning Enabled Smart Drying
- Mechanical Modeling and Computer Software Tracking
- Product Microstructure and Surface Metrology Characterization
- No-Phase-Change Dehydration Schemes and Other Novel Drying Concepts
- Innovative Impinging Jets with and without Chemical Reactions for Drying, Heating, and Cooling Applications
- Energy Auditing
- Development of Unique Sensors

Research in CARD is directed by Prof. J. Yagoobi. Further information and a list of participating faculty members can be found at http://www.dryingresearch.org/.

Return to Table of Contents

Center for Holographic Studies and Laser micro-mechaTronics

The laboratories of the Center for Holographic Studies and Laser micro-mechaTronics (CHSLT) cover over 2,800 sq. ft and support activities ranging from fundamental studies of laser light interaction with materials to sophisticated applications in metrology. Research at the CHSLT is externally funded in areas relating to electronic packaging, high density separable electronic interconnections for high speed digital applications, radar technology, microelectronics, micromechanics, submarine technology, jet engine technology, MEMS, nanotechnology and picotechnology, to name a few. The laboratories are furnished with He-Ne lasers, Ar-ion lasers, Nd:YAG lasers, nanosecond high energy pulsed laser, and diode lasers, as well as supporting instrumentation systems. In addition, the Nano-Indentation (NIN) system is being developed for studies of mechanical properties of materials in sub-micron geometries. The CHSLT has its own computational facilities for Finite Element, Finite Difference, and Boundary Element analysis, modeling, and simulation. The metrological applications at the CHSLT concentrate on holographic interferometry, laser speckle metrology, fiber optic sensors, analytical and computational modeling of structural behavior under static as well as dynamic loading conditions, and other areas of current interest. In the area of holographic interferometry, the CHSLT maintains holographic systems for studies of static as well as dynamic problems. These systems range from conventional double-exposure holography, to real-time and time-average holography, heterodyne holography, stroboscopic heterodyne holography, pulsed laser holography, and electro-optic holography (EOH). The EOH system allows for direct electronic acquisition and processing of interferometric data in real-time and sets a new standard for quantitative holographic analysis. The CHSLT also conducts experimental and computational research in the field of nanoindentation studies in conjunction with a laboratory system which is uniquely suited to measure elastic, plastic, creep, and fracture properties of materials in submicron geometries. In addition, the CHSLT is equipped with a complete laser vibrometer system, GHz frequency range storage oscilloscopes, a spectrum analyzer, a self-contained network of personal computers, UNIX based workstations and image processors, a host of supporting instrumentation, and a library of finite element analysis and general purpose software. A well-equipped electrical engineering and instrument development laboratory, a fiber optic preparation laboratory, an optical microscopy laboratory and a multifunctional dark room are also parts of the CHSLT. The strengths of the CHSLT lie in a comprehensive utilization of laser technology, optics, computational methods, mechanical engineering, materials science and engineering, and computer data acquisition and processing. Research in CHSLT is directed by Prof. C. Furlong. Further information can be found at http://chslt.wpi.edu/.

Course Descriptions

All courses are 3 credits unless otherwise noted.

General:

ME 5000. Applied Analytical Methods in Engineering

(2 credits)

The emphasis of this course is on the modeling of physical phenomena encountered in typical engineering problems, and on interpreting solutions in terms of the governing physics. In this manner, the course will expose students to a range of techniques that are useful to practicing engineers and researchers. Physical examples will be drawn from fluid mechanics, dynamics, stability problems, and structural mechanics. The course will introduce analytical techniques as they are required to study such phenomena. Depending on the examples chosen, the techniques covered may include partial differential equations, power series, Fourier series, Fourier integrals, including cases of sustained non-periodic processes which require incorporating probabilistic approach into dynamics, Green's Functions, Sturm-Liouville theory and linear algebra. (Prerequisites: differential equations at the undergraduate level.) Students cannot receive credit for this course if they have taken either the Special Topics (ME 593A) version of the same course or ME 500.

ME 5001. Applied Numerical Methods in Engineering

(2 credits)

A study of important numerical and computational methods for solving engineering science problems. The course will include methods for solving linear and nonlinear equations, interpolation strategies, evaluating integrals, and solving ordinary and partial differential equations. Finite difference methods will be developed in full for the solution of partial differential equations. The course materials emphasize the systematic generation of numerical methods for elliptic, parabolic, and hyperbolic problems, and the analysis of their stability, accuracy, and convergence properties. The student will be required to write and run computer programs. Students cannot receive credit for this course if they have taken the Special Topics (ME 593M) version of the same course or ME 515.

Fluids Engineering:

ME/AE 5101. Fluid Dynamics

(2 credits)

This course presents the following fundamental topics in fluid dynamics: concept of continuum in fluids; kinematics and deformation for Newtonian fluids; the mass conservation equation, momentum and energy equations for material volumes and control volumes; the differential form of mass conservation, momentum and energy equations. This course covers also applied topics chosen from: unidirectional steady incompressible viscous flows; unidirectional transient incompressible viscous flows; lubrication flows similarity and dimensional analysis. This is an introductory graduate-level course and may be taken independent of AE 5107/ME 5107.

ME/AE 5104. Turbomachinery

(2 credits)

This course is an introduction to the fluid mechanics and thermodynamics of turbo-machinery for propulsion and power generation applications. Axial and centrifugal compressors will be discussed as well as axial and radial flow turbines. Analysis of the mean line flow in compressor and turbine blade rows and stages will be discussed. The blade-to-blade flow model will be presented and axisymmetric flow theory introduced. Three-dimensional flow, i.e. secondary flows, will also be discussed. Students cannot receive credit for this course if they have taken the Special Topics (ME 593H) version of the same course.

ME/AE 5105. Renewable Energy

(2 credits)

The course provides an introduction to renewable energy, outlining the challenges in meeting the energy needs of humanity and exploring possible solutions in some detail. Specific topics include: use of energy and the correlation of energy use with the prosperity of nations; historical energy usage and future energy needs; engineering economics; electricity generation from the wind; wave/ocean energy, geo-thermal and solar-thermal energy; overview of fuel cells, biofuels, nuclear energy, and solar-photovoltaic systems and their role and prospects; distribution of energy and the energy infrastructure; energy for transportation; energy storage. Pre-requisites; ES3001, ES3004 or equivalents.

ME/AE 5107. Applied Fluid Dynamics
(2 credits)
This course presents applications of incompressible and compressible fluid dynamics at an introductory graduate level. Topics are chosen from: potential flows; boundary layers; vorticity dynamics and rotating flows; aerodynamics; introduction to turbulence; micro/nano flows. This course can be taken independent of AE 5101/ME 5101.

ME/AE 5108. Introduction to Computational Fluid Dynamics
(2 credits)
The course provides the theory and practice of computational fluid dynamics at an entry graduate level. Topics covered include: classification of partial differential equations (PDEs) in fluid dynamics and characteristics; finite difference schemes on structured grids; temporal discretization schemes; consistency, stability and error analysis of finite difference schemes; explicit and implicit finite differencing schemes for 2D and 3D linear hyperbolic, parabolic, elliptic, and non-linear PDEs in fluid dynamics; direct and iterative solution methods for algebraic systems. The course requires completion of several projects using MATLAB.

ME 513. Thermodynamics
(3 credits)
Review of the zeroth, first and second laws of thermodynamics and systems control volume. Applications of the laws to heat engines and their implications regarding the properties of materials. Equations of state and introduction to chemical thermodynamics.

ME 516. Heat Transfer
(3 credits)
Review of governing differential equations and boundary conditions for heat transfer analysis. Multidimensional and unsteady conduction, including effects of variable material properties. Analytical and numerical solution methods. Forced and free convection with laminar and turbulent flow in internal and external flows. Characteristics of radiant energy spectra and radiative properties of surfaces. Radiative heat transfer in absorbing and emitting media. Systems with combined conduction, convection and radiation. Condensation, evaporation, and boiling phenomena. (Prerequisite: Background in thermodynamics, fluid dynamics, ordinary and partial differential equations, and basic undergraduate physics.)

ME/AE 6108. Intermediate Computational Fluid Dynamics
(2 credits)
The course presents computational methods for incompressible and compressible viscous flows at an intermediate level. Topics are chosen from: grid generation techniques; finite volume schemes; stability analysis; artificial viscosity; explicit and implicit schemes; flux-vector splitting; monotonic advection schemes; multigrid methods; particle-based simulation methods. (Prerequisite: fluid dynamics; an introductory course in numerical methods for partial differential equations; programming language experience) Students who have received credit for AE/ME 5103 will not receive credit for AE/ME 6108.

Dynamics and Controls:

ME 501/RBE 501. Robot Dynamics
(3 credits)
Foundations and principles of robotic manipulation. Topics include computational models of objects and motion, the mechanics of robotic manipulators, the structure of manipulator control systems, planning and programming of robot actions. The focus of this class is on the kinematics and programming of robotic mechanisms. Important topics also include the dynamics, control, sensor and effector design, and automatic planning methods for robots. The fundamental techniques apply to arms, mobile robots, active sensor platforms, and all other computer-controlled kinematic linkages. The primary applications include robotic arms and mobile robots, and lab projects would involve programming of representative robots. An end-of-term team project would allow students to program robots to participate in challenges or competitions. (Prerequisite: RBE 500 or equivalent.)

ME 5200. Mechanical Vibrations
(2 credits)
The course provides fundamentals for vibration analysis of linear discrete and continuous dynamic systems, A vibrating system is first modeled mathematically as an initial value problem (IVP) or a boundary-initial value problem (BIVP) by the Newton-D'Alembert method and/or the Lagrange energy approach and then solved for various types of system. Explicit solutions for dynamic response of a linear single-degree-of-freedom (SDOF) system, both damped and undamped, is derived for free-vibration caused by the initial conditions and forced vibration caused by different excitations. Modal analysis is presented to solve for vibration response of both multi-degree-of-freedom (MDOF) systems and continuous systems with distributed parameters. As the basis of modal analysis, the natural frequencies and vibration modes of a linear dynamic system are obtained in advance by solving an associated generalized eigenvalue problem and the orthogonal properties of the vibration modes with respect to the stiffness and mass matrices are strictly proved. Computational methods for vibration analysis are introduced. Applications include but are not limited to cushion design of falling packages, vehicles traveling on a rough surface, multi-story building subjected to seismic and wind loading, and vibration analysis of bridges subjected to traffic loading. Students cannot receive credit for this course if they have taken the Special Topics (ME 593V) version of the same course or ME522.

ME 5202. Advanced Dynamics
(2 credits)
Basic concepts and general principles of classical kinematics and dynamics of particles, systems of particles and rigid bodies are presented with application to engineering problems with complicated three-dimensional kinematics and dynamics. Derivation of the governing equations of motion using Principle of Virtual Work and Lagrange equations is described together with the direct Newton approach. Applications include: swings-effect and its use in engineering, illustrating in particular limit cycles and their stability and reversed-swings control of vibrations of pendulum; various examples of gyroscopic effects; and especially introductory rotordynamics including transverse vibrations (whirling) and potential instability of rotating shafts. Students cannot receive credit for this course if they have taken the Special Topics (ME 593D) version of the same course or ME 527.

ME 5204/RBE 510. Multi-Robot Systems
(2 credits)
This course covers the foundation and principles of multi-robot systems. The course will cover the development of the field and provide an overview on different control architectures (deliberative, reactive, behavior-based and hybrid control), control topologies, and system configurations (cellular automata, modular robotic systems, mobile sensor networks, swarms, heterogeneous systems). Topics may include, but are not limited to, multi-robot control and connectivity, path planning and localization, sensor fusion and robot informatics, task-level control, and robot software system design and implementation. These topics will be pursued through independent reading, class discussion, and a course project. The course will culminate in a group project focusing on a collaborative/cooperative multi-robot system. The project may be completed through simulation or hands-on experience with available robotic platforms. Groups will present their work and complete two professional-quality papers in IEEE format. (Prerequisites: Linear algebra, differential equations, linear systems, controls, and mature programming skills, or consent of the instructor.) Students cannot receive credit for this course if they have taken the Special Topics (ME 593S) version of the same course.

ME 5205/RBE 580. Biomedical Robotics
(2 credits)
This course will provide an overview of a multitude of biomedical applications of robotics. Applications covered include: image-guided surgery, percutaneous therapy, localization, robot-assisted surgery, simulation and augmented reality, laboratory and operating room automation, robotic rehabilitation, and socially assistive robots. Specific subject matter includes: medical imaging, coordinate systems and representations in 3D space, robot kinematics and control, validation, haptics, teleoperation, registration, calibration, image processing, tracking, and human-robot interaction.Topics will be discussed in lecture format followed by interactive discussionof related literature. The course will culminate in a team project covering one or more of the primary course focus areas. Recommended background: Linear algebra, ME/RBE 501 or equivalent Students cannot receive credit for this course if they have taken the Special Topics (ME 593U) version of the same course.

ME/RBE 521. Legged Robotics
Foundations and principles of parallel manipulators and legged robots. Topics include advanced spatial/3D kinematics and dynamics of parallel manipulators and legged robots including workspace analysis, inverse and forward kinematics and dynamics, motion analysis and control, and gait and stability/balance analysis of legged robots. The course will be useful for solving problems dealing with parallel manipulators as well as multi-legged robots including, but not limited to, quadruped robots, hexapod robots and any other types of multi-legged robots. A final term project allows students to show mastery of the subject by designing, analyzing, and simulating parallel and/or legged robots of their choice.
Recommended Background: RBE 500, RBE 501.

ME/AE 5220. Control of Linear Dynamical Systems
(2 credits)
This course covers analysis and synthesis of control laws for linear dynamical systems. Fundamental concepts including canonical representations, the state transition matrix, and the properties of controllability and observability will be discussed. The existence and synthesis of stabilizing feedback control laws using pole placement and linear quadratic optimal control will be discussed. The design of Luenberger observers and Kalman filters will be introduced. Examples pertaining to aerospace engineering, such as stability analysis and augmentation of longitudinal and lateral aircraft dynamics, will be considered. Assignments and term project (if any) will focus on the design, analysis, and implementation of linear control for current engineering problems. The use of Matlab®/Simulink® for analysis and design will be emphasized. (Recommended background: Familiarity with ordinary differential equations, introductory control theory, fundamentals of linear algebra, and the analysis of signals and systems is recommended. Familiarity with Matlab® is strongly recommended.)

ME/AE 5221. Control of Nonlinear Dynamical Systems
(2 credits)
Overview of stability concepts and examination of various methods for assessing stability such as linearization and Lyapunov methods. Introduction to various design methods based on linearization, sliding modes, adaptive control, and feedback linearization. Demonstration and performance analysis on engineering systems such as flexible robotic manipulators, mobile robots, spacecraft attitude control and aircraft control systems. Control synthesis and analysis is performed using Matlab®/Simulink®. (Prerequisites: Familiarity with ordinary differential equations, introductory control theory at the undergraduate level, fundamentals of linear algebra. Familiarity with Matlab® is strongly recommended.)

ME 5225. Fiber Optical Sensors
(2 Credits)
This course is designed to introduce students to the field of fiber optics, with an emphasis on design and working principles of fiber optical sensors for mechanical, biological, and chemical measurements. Students will be able to learn the basic knowledge and working principles of optical fibers and fiber optical components, as well as practical design guidelines and applications of fiber optical sensing systems. The first half of the course will introduce the fundamentals of fiber optics, including working principles of optical fibers, single-mode and multimode fibers, properties of optical fibers, passive fiber optical devices, light sources, and optical detectors. The second half will focus on practical fiber optical sensors and sensing systems, including working principles of fiber optical sensors, intensity-based and interferometer-based fiber optical sensors, fiber Bragg gratings, and low-coherence fiber optical interferometers. Specifically, design and implementation of fiber optical sensors and sensing systems for strain and pressure measurements will be discussed in detail. Measurement characteristics and signal processing of fiber optical sensing systems for different applications will be introduced. Recommended Background: Undergraduate level stress analysis and wave fundamentals, such as ES 2502, PH 1140. Knowledge of vibrations such as ME 4506 is preferred but not required.

ME/RBE 530. Soft Robotics
(2 credits)
Soft robotics studies "intelligent" machines and devices that incorporate some form of compliance in their mechanics. Elasticity is not a byproduct but an integral part of these systems, responsible for inherent safety, adaptation and part of the computation in this class of robots. This course will cover a number of major topics of soft robotics including but not limited to design and fabrication of soft systems, elastic actuation, embedded intelligence, soft robotic modeling and control, and fluidic power. Students will implement new design and fabrication methodologies of soft robots, read recent literature in the field, and complete a project to supplement the course material. Existing soft robotic platforms will be available for experimental work. Prerequisites: Differential equations, linear algebra, stress analysis, kinematics, embedded programming.

ME 6201. Advanced Topics in Vibration
(2 credits)
The course presents advanced topics in vibrations of machines and structures: dynamic stability analysis for linear nonconservative systems with applications to aeroelasticity and rotordynamics such as whirling of shafts with internal energy dissipation; introduction into theory of nonlinear and parametric vibrations in machines and structures; probabilistic approach in dynamics – analysis of random vibrations with applications to reliability evaluation in earthquake engineering, offshore engineering, etc. Use of random vibration analyses is illustrated for online condition monitoring for machines and structures (mechanical signature analysis), such as detecting instability and evaluating stability margin for a nonconservative system from its online measured signal. Introduction into general vibration theory makes the course self-contained (background in ME 522 preferable but not necessary). Students cannot receive credit for this course if they have taken the Special Topics (ME 593B) version of the same course.

ME 621. Dynamics and Signal Analysis
(3 credits)
A laboratory-based course which applies Fourier and cepstral signal analysis techniques to mechanical engineering problems. The theory and application of the Fourier series, Fast Fourier Transform (FFT) and the cepstrum to the analysis of mechanical and acoustical systems is presented. Digital sampling theory, windowing, aliasing, filtering, noise averaging and deconvolution are discussed. Limitations of and errors in implementation of these techniques are demonstrated. Students will perform weekly experiments in the Structural Dynamics and Vibration Laboratory, which reinforce the theories presented in lectures. Application will include structures, acoustics, rotating machinery and cams.

Structures and Materials:

ME/CE 5303. Applied Finite Element Methods in Engineering

(2 credits)

This course is devoted to the numerical solution of partial differential equations encountered in engineering sciences. Finite element methods are introduced and developed in a logical progression of complexity. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium and transient problems. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class. Students cannot receive credit for this course if they have taken the Special Topics (ME 593E) version of the same course or ME 533 or CE 524.

ME 5304. Laser Metrology and Nondestructive Testing

(2 credits)

Demands for increased performance and efficiency of components in the nano/micro-, meso-, and macro-scales, impose challenges to their engineering design, study, and optimization. These challenges are compounded by multidisciplinary applications to be developed inexpensively in short time while satisfying stringent design objectives. As a consequence, effective quantitative engineering methodologies, such as optical techniques, are frequently used in the study and optimization of advanced components and systems. In this course, modern laser metrology techniques are discussed and their practical applications to solve problems, with emphasis on nondestructive testing (NDT), are illustrated with laboratory demonstrations. Topics covered include wave and Fourier optics, classic and holographic interferometry, speckle techniques, solid-state lasers, fiber optics, CCD cameras, computer vision, camera calibration methods, and image processing and data reduction algorithms as required in quantitative fringe analysis. Detail examples of nondestructive testing and coherent optical metrology in solid mechanics, vibrations, heat transfer, electromagnetics, and reverse engineering are given. Students are required to work on projects depending on their background and interests. Recommended background: mechanics, materials, physics, knowledge of a high-level computer programming language. Students cannot receive credit for this course if they have taken the Special Topics (ME 593J) version of the same course or ME 534.

ME 5311/MTE 511. Structure and Properties of Engineering Materials

(2 credits)

This course, (along with its companion course MTE 512 Properties and Performance of Engineering Materials), is designed to provide a comprehensive review of the fundamental principles of Materials Science and Engineering for incoming graduate students. In the first part of this 2-course sequence, the structure in materials ranging from the sub-atomic to the macroscopic including nano, micro and macromolecular structures will be discussed to highlight bonding mechanisms, crystallinity and defect patterns. Representative thermodynamic and kinetic aspects such as diffusion, phase diagrams, nucleation and growth and TTT diagrams will be discussed. Major structural parameters that effect of performance in materials including plastics, metallic alloys, ceramics and glasses will be emphasized. The principal processing techniques to shape materials and the effects of processing on structure will be highlighted. (Prerequisites: senior or graduate standing or consent of the instructor.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594S).

ME 5312/MTE 512. Properties and Performance of Engineering Materials

(2 credits)

The two introductory classes on materials science (MTE 511 and MTE 512) describe the structure-property relationships in materials. The purpose of this class is to provide a basic knowledge of the principles pertaining to the physical, mechanical and chemical properties of materials. The primary focus of this class will be on mechanical properties. The thermal, tensile, compressive, flexural and shear properties of metallic alloys, ceramics and glasses and plastics will be discussed. Fundamental aspects of fracture mechanics and viscoelasticity will be presented. An overview of dynamic properties such as fatigue, impact and creep will be provided. The relationship between the structural parameters and the preceding mechanical properties will be described. Basic composite theories will be presented to describe fiber-reinforced composites and nanocomposites. Various factors associated with material degradation during use will be discussed. Some introductory definitions of electrical and optical properties will be outlined. (Prerequisites: senior or graduate standing or consent of the instructor.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594P).

ME 5313. Introduction to Nanomechanics

(2 credits)

This course introduces students to nanomechanics. Topics covered include an introduction to mechanical systems, forces at the nano to atomic scales, cantilever theory, mechanics of 0D, 1D and 2D nanomaterials, polymer chain nanomechanics, molecular recognition, wear friction and adhesion at the nanoscale, scale dependence of frictional resistance, nano-indentation, surface elasticity and viscoelasticity mapping, lubrication principles at the nanoscale, interfacial forces in confined fluids, mechanics of electrorheological and magnetic fluids. Recommended Background: ME 4875 or consent of Instructor.

ME 5356/MTE 556. Smart Materials

(2 credits)

A material whose properties can respond to an external stimulus in a controlled fashion is referred to as a smart or intelligent material. These materials can be made to undergo changes modulus, shape, porosity, electrical conductivity, physical form, opacity, and magnetic properties based on an external stimulus. The stimuli can include temperature, pH, specific molecules, light, magnetic field, voltage and stress. These stimuli-sensitive materials can be utilized as sensors and as vehicles for the controlled delivery of drugs and other biomolecules in medical applications. Smart materials are also becoming important in other biological areas such as bio-separation, biosensor design, tissue engineering, protein folding, and microfluidics. The use of stimuli-sensitive materials is receiving increasing attention in the development of damage tolerant smart structures in aerospace, marine, automotive and earth quake resistant buildings. The use of smart materials is being explored for a range of applications including protective coatings, corrosion barriers, intelligent batteries, fabrics and food packaging. The purpose of this course is to provide an introduction to the various types of smart materials including polymers, ceramic, metallic alloys and composites. Fundamental principles associated with the onset of "smart" property will be highlighted. The principles of self-healable materials based on smart materials will be discussed. The application of smart materials in various fields including sensors, actuators, diagnostics, therapeutics, packaging and other advanced applications will be presented. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594X).

ME 5358/MTE 558. Plastics

(2 credits)

This course will provide an integrated overview of the design, selection and use of synthetic plastics. The basic chemistry associated with polymerization and the structure of commercial plastics will be described. Various aspects of polymer crystallization and glass transition will be outlined. Salient aspects of fluid flow and heat transfer during the processing of plastics will be highlighted. Fundamentals of the diverse processing operations used to shape plastics and the resulting structures that develop after processing will be discussed. The mechanical behavior of plastics including elastic deformation, rubber elasticity, yielding, viscoelasticity, fracture and creep will be discussed. Plastic degradation and environmental issues associated with recycling and disposal of plastics will be examined. Typical techniques used in the analysis and testing of plastics will be described and a working knowledge of various terminologies used in commercial practice will be provided. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 594A).

ME 5361/MTE 561. Mechanical Behavior and Fracture of Materials

(2 credits)

The failure and wear-out mechanisms for a variety of materials (metals, ceramics, polymers, composites and microelectronics) and applications will be presented and discussed. Multi-axial failure theories and fracture mechanics will be discussed. The methodology and techniques for reliability analysis will also be presented and discussed. A materials systems approach will be used. (Prerequisites: ES 2502 and ME 3023 or equivalent, and senior or graduate standing in engineering or science.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MTE 593C/MTE 594C).

ME 5370/MTE 5841/MFE 5841. Surface Metrology

(3 credits)

This course emphasizes research applications of advanced surface metrology, including the measurement and analysis of surface roughness. Surface metrology can be important in a wide variety of situations including adhesion, friction, catalysis, heat transfer, mass transfer, scattering, biological growth, wear and wetting. These situations impact practically all the engineering disciplines and sciences. The course begins by considering basic principles and conventional analyses, and methods. Measurement and analysis methods are critically reviewed for utility. Students learn advanced methods for differentiating surface textures that are suspected of being different because of their performance or manufacture. Students will also learn methods for making correlations between surface textures and behavioral and manufacturing parameters. The results of applying these methods can be used to support the design and manufacture of surface textures, and to address issues in quality assurance. Examples of research from a broad range of applications are presented, including, food science, pavements, friction, adhesion, machining and grinding. Students do a major project of their choosing, which can involve either an in-depth literature review, or surface measurement and analysis. The facilities of WPI's Surface Metrology Laboratory are available for making measurements for selected projects. Software for advanced analysis methods is also available for use in the course. No previous knowledge of surface metrology is required. Students should have some background in engineering, math or science.

ME/AE 5380. Foundations of Elasticity

(2 credits)

This course is suitable as an introductory graduate level course. Topics will be chosen from the following: three-dimensional states of stress; measures of strain; thick-walled cylinders, disks and spheres; plane stress and plane strain; thermoelasticity; Airy stress function; energy methods, and exact theory for torsion of non-circular cross sections. This course may be taken independent of ME 5302.

ME/AE 5381. Applied Elasticity

(2 credits)

This course is suitable as an introductory graduate level course. Topics covered will be chosen from the following: bending and shear stresses in unsymmetric beams; bending of composite beams; bending of curved beams; torsion of thin-walled noncircular cross sections; beams on elastic foundations; stress concentrations; failure criteria; stability of columns; and bending of plates. This course may be taken independent of ME 5301.

ME 5383/CE 514. Continuum Mechanics

(2 credits)

This course covers the fundamentals of continuum mechanics at an introductory graduate level. Topics covered include: 1) Introduction: essential mathematics - scalars, vectors, tensors, and indicial notation; 2) Basics: three-dimensional states of stress, finite and infinitesimal measures strain, and principal axes; 3) Conservations laws: mass, linear momentum, angular momentum and energy; 4) Constitutive equations: ideal materials, Newtonian fluids, isotropy and anisotropy, elasticity and thermoelasticity, plasticity, and viscoelasticity; 5) Applications to classical problems and emerging topics in solid and fluid mechanics. Recommended background: undergraduate knowledge of strength of materials, fluid mechanics, and linear algebra.

ME 634. Holographic Numerical Analysis

(3 credits)

Recent advances in holographic analysis of body deformations are discussed. Included in the course are topics covering sandwich holography, optoelectronic fringe interpolation technique, theory of fringe localization, use of projection matrices and the fringe tensor theory of holographic strain analysis. The application of interactive computer programs for holographic analysis of engineering and biological systems will be outlined. Lectures are supplemented by laboratory demonstrations and experiments. (Prerequisites: Matrix algebra, vector calculus and consent of instructor.)

Design and Manufacturing:

ME 5401. Computer-Aided Design and Geometric Modeling

(2 credits)

This course covers topics in computer-aided geometric design and applications in mechanical engineering. The objectives of the course are to familiarize the students with complex geometric modeling and analytical techniques used in contemporary computer-aided design systems. Topics to be covered may include complex curve and surface generation, solid modeling, assembly and mechanism modeling, transformations, analytic geometry, offsets and intersections of complex shapes, graphics standards and data transfer, rendering techniques, parametric design and geometric optimization, numerical methods for geometric analysis and graphics design programming. Prerequisites: calculus, linear algebra, introductory computer programming, and ability to utilize a solid modeling CAD system. Students cannot receive credit for this course if they have taken the Special Topics (ME 593C) version of the same course or ME 545.

ME/MFE/MTE 5420. Fundamentals of Axiomatic Design of Manufacturing Processes

(2 credits)

The course starts with an in-depth study of axiomatic design. Applications of axiomatic design are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is a design methodology based on the premise that there are two axioms that apply to all good designs. These axioms facilitate the teaching and practice of engineering design as a scientific discipline. Manufacturing process analysis is considered from the perspective of supporting design. Methods of analysis of manufacturing processes with broad applicability are sought. Special attention is given to examples in machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surfaces. The ability to find commonalities across applications and generalize is emphasized to facilitate further development of principles with broad applicability. The content is delivered in video lectures and in readings from the technical literature. Homework and quizzes are given and delivered online. There is a project to design a manufacturing process. The topics can be from work or dissertations that can be interpreted as manufacturing processes and tools.

Credit cannot be given for this course and any of the similar, in-class versions for 3 credits, MFE 520, MTE 520 and ME 543.

ME 543/MFE 520/MTE 520. Axiomatic Design of Manufacturing Processes
(3 credits)

This course begins with elements axiomatic design, the theory and practice. Design applications are considered primarily, although not exclusively, for the design of manufacturing processes and tools. Axiomatic design is based on the premise that there are common aspects to all good designs. These commons aspects, stated in the independence and information axioms, facilitate the teaching and practice of engineering design as a scientific discipline. Analysis of processes and products is considered from the perspective of supporting product and process design. Fundamental methods of engineering analysis of manufacturing processes with broad applicability are developed. Attention is given to examples from one or more of the following: machining (traditional, nontraditional and grinding), additive manufacturing, and to the production of surface topographies. The ability to generalize from detailed examples is emphasized in order to facilitate the students' ability to development analyses and design methods with broader applicability.

This course is offered live, in-class only, to be completed in one semester, for three credits. Credit cannot be given for this course and any of the similar, online versions of this material for 2 credits: MFE521, MTE521 and ME521.

ME 5431/MFE 531. Computer Aided Manufacturing
(2 credits)

An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. Emphasis is placed on CAD/CAM integration. Topics include, part design specification and manufacturing quality, tooling and fixture design, and manufacturing information systems. This course includes a group term project. (Prerequisites: Background in manufacturing and CAD/CAM, e.g., ME 1800, ES 1310, ME 3820.) Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (ME 593D/MFE 594D).

ME 5441/MFE 541. Design for Manufacturability
(2 credits)

The problems of cost determination and evaluation of processing alternatives in the design-manufacturing interface are discussed. Approaches for introducing manufacturing capability knowledge into the product design process are covered. An emphasis is placed on part and process simplification, and analysis of alternative manufacturing methods based on such parameters as: anticipated volume, product life cycle, lead time, customer requirements, and quality yield. Lean manufacturing and Six-Sigma concepts and their influence on design quality are included as well. Note: Students cannot receive credit for this course if they have taken the Special Topics version of the same course (MFE 594M).

Biomechanical Engineering:

ME 550/BME 550. Tissue Engineering
(3 credits)

This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented. (Recommended preparation: A first course in biomaterials equivalent to ME/BME 4814 and a basic understanding of physiology and cell biology.)

ME 552/BME 552. Tissue Mechanics
(3 credits)

This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues, and their relationship to physiological processes. Applications include tissue injury, wound healing, the effect of pathological conditions upon tissue properties and design of medical devices and prostheses. (Recommended preparation: A first course in biomechanics equivalent to ME/BME 4504.)

Other Activities:

ME 591. Graduate Seminar
(0 credits)

Seminars on current issues related to various areas of mechanical engineering are presented by authorities in their fields. All full-time mechanical engineering students are required to register and attend.

ME 593. Special Topics
(credits TBD)

Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Department well in advance of the offering. (Prerequisite: Consent of instructor.)

ME 598. Directed Research
(credits TBD)

For M.S. students wishing to gain research experience peripheral to their thesis topic, or for Ph.D. students wishing to gain research experience peripheral to their dissertation topic..

ME 599. Thesis Research
(credits TBD)

For master's students wishing to obtain research credit toward their thesis. (Prerequisite: Consent of Thesis Advisor.)

ME 693. Advanced Special Topics
(credits TBD)

Arranged by individual faculty with special expertise, these courses cover advanced topics that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Department well in advance of the offering. (Prerequisite: Consent of instructor.)

ME 698. Pre-Dissertation Research
(credits TBD)

Intended for doctoral students wishing to obtain dissertation-research credit prior to admission to candidacy. (Prerequisite: Consent of Dissertation Advisor.)

ME 699. Dissertation Research
(credits TBD)

Intended for doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations. (Prerequisite: Consent of Dissertation Advisor.)

Return to Table of Contents

Affiliated Faculty

J. Srinivasan, Associate Professor, Biology and Biotechnology and Program Director, Neuroscience; Ph.D., University of Tuebingen, Germany; neural networks underlying social behaviors, role of olfactory dysfunction in neurodegenerative disorders, optogenetics & engineering of neural networks.

D. R. Albrecht, Associate Professor, Biomedical Engineering; Ph.D., University of California, San Diego; bioMEMS, microfluidics, quantitative systems analysis and modeling, biodynamics, neural circuits and behavior, optogenetics, high-throughput chemical/genetic screens, tissue engineering, 3-D cell micropatterning, dielectrophoresis.

A. Arnold, Assistant Professor, Mathematical Sciences; Ph.D., Case Western University, 2014. Mathematical biology, bayesian inference, parameter estimation in biological systems.

S. Barton, Associate Professor, Humanities and Arts; Ph.D. University of Virginia, 2012. Human- robot interaction in music composition and performance, design of robotic musical instruments, music perception and cognition, audio production.

F. Bianchi, Professor, Humanities & Arts;

K. L. Billiar, Professor and Department Head, Biomedical Engineering; Ph.D., University of Pennsylvania; Biomechanics of soft tissues and biomaterials, mechanobiology, wound healing, tissue growth and development; functional tissue engineering, regenerative medicine.

S. C. Burdette, Associate Professor, Chemistry and Biochemistry; Ph.D., Massachusetts Institute of Technology; synthesis of fluorescent sensors for iron, photoactive chelators for delivery of metal ions in cells, applications of azobenzene derivatives with unusual optical properties, polymers to detect metal contaminants in the environment.

L. Capogna, Professor and Department Head, Mathematical Sciences; Ph.D., Purdue University, 1996. Partial differential equations.

R. E. Dempski, Associate Professor, Chemistry and Biochemistry; Ph.D., Massachusetts Institute of Technology; molecular mechanism of human zinc transporter, structure-function of light activated channel, optogenetics.

J. Doyle, Associate Professor, Social Science and Policy Studies; Ph.D., University of Colorado-Boulder, 1991. Mental models of complex systems, environmental cognition and behavior.

J. B. Duffy, Associate Professor and Department Head, Biology and Biotechnology; Ph.D., University of Texas; defining signaling pathways that program cellular diversity.

M. Elmes, Professor, Robert A. Foisie School of Business; Ph.D., Syracuse University, 1998. Interpersonal and group dynamics in complex organizations, leading change, leadership ethics.

R. Falco, Assistant Teaching Professor, Humanities & Arts;

N. Farny, Assistant Professor, Biology and Biotechnology; Ph.D., Harvard University, 2009. Translational control of gene expression and cellular stress response in neurodegenerative disease and autism spectrum disorder.

A. Gericke, Professor and Department Head, Chemistry and Biochemistry; Dr.rer.nat., University of Hamburg; biophysical characterization of lipid-mediated protein function, development of vibrational spectroscopic tools to characterize biological tissue.

L. Harrison, Assistant Professor, Computer Science; Ph.D., UNC-Charlotte, 2013. Information visualization, visual analytics, human-computer interaction.

M. Humi, Professor, Mathematical Sciences; Ph.D., Weizmann Institute of Science, 1969. Mathematical physics, applied mathematics and modeling, Lie groups, differential equations, numerical analysis, turbulence and chaos.

S. Ji, Associate Professor, Biomedical Engineering; D.Sc., Washington University in St. Louis; Biomechanics, brain injury, finite element analysis, multi-scale modeling, neuroimaging, medical image analysis, sports medicine.

J. A. King, Professor, Biology and Biotechnology and Peterson Family Dean of Arts and Sciences; Ph.D., New York University; M.S, City University of New York; neuronal plasticity associated with neurological and psychiatric disorders utilizing functional magnetic resonance imaging, molecular biology and behavior.

X. Kong, Associate Professor, Computer Science; Ph.D., University of Illinois, Chicago, IL 2014. Data mining, social networks, machine learning, big data analytics.

D. Korkin, Professor, Computer Science; Ph.D., University of New Brunswick, Canada, 2003. Bioinformatics of disease, big data in biomedicine, computational genomics, systems biology, data mining, machine learning.

K. Lee, Assistant Professor, Biomedical Engineering; Ph.D., Massachusetts Institute of Technology; mechanobiology, cell mechanics, cell morphodynamics, cancer cell migration, quantitative live cell imaging, quantitative cell biology, computational image analysis, data mining, genome engineering, optogenetics.

Y. Mendelson, Professor, Biomedical Engineering; Ph.D., Case Western Reserve University; Biomedical sensors for invasive and noninvasive physiological monitoring, pulse oximeters, microcomputer-based medical instrumentation, signal processing, wearable wireless biomedical sensors, application of optics to biomedicine, telemedicine.

R. Neamtu, Associate Teaching Professor, Computer Science; Ph.D., Worcester Polytechnic Institute;

S. Olson, Associate Professor, Mathematical Sciences; Ph.D., North Carolina State University 2008. Mathematical biology, computational biofluids, scientific computing.

M. B. Popovic, Assistant Research Professor, Physics; Ph.D., Boston University. Human neurosensory-motor organization, soft robotics, wearable robotics, assistive robotics, human augmentation systems.

Return to Table of Contents

A. Rodriguez, Assistant Professor, Social Science & Policy Studies; Ph.D., University of California, Los Angeles;

C. Ruiz, Professor, Computer Science; Ph.D., Maryland, 1996. Data mining, knowledge discovery in databases, machine learning.

E. F. Ryder, Associate Professor, Biology and Biotechnology; Ph.D., Harvard University; M.S., Harvard School of Public Health; bioinformatics and computational approaches to understanding biological systems.

S. F. Scarlata, Professor, Chemistry and Biochemistry; Ph.D., University Illinois Urbana-Champaign; Mechanisms of cell signaling using fluorescence imaging and correlation methods, how mechanical deformation affects calcium fluxes in cells.

J. L. Skorinko, Professor, Social Science & Policy Studies; Ph.D., University of Virginia; soc ial environmental cues, stigmas and stereotyping, perceptions of others

E. T. Solovey, Assistant Professor, Computer Science; Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.

I. Stroe, Associate Teaching Professor, Physics; Ph.D., Clark University. Experimental biophysics, protein structure, dynamic, and functionality.

D. Tang, Professor, Mathematical Sciences; Ph.D., University of Wisconsin, 1988. Biofluids, biosolids, blood flow, mathematical modeling, numerical methods, scientific computing, nonlinear analysis, computational fluid dynamics.

L. V. Titova, Associate Professor, Physics; Ph.D., University of Notre Dame. THz spectroscopy of nanomaterials for energy applications; optical excitations and ultrafast carrier dynamics in nanomaterials.

L. Vidali, Associate Professor, Biology and Biotechnology; Ph.D., University of Massachusetts-Amherst; understanding the molecular and cellular mechanisms underlying the role of the cytoskeleton in plant cell organization and growth.

C. E. Wills, Professor and Department Head, Computer Science; Ph.D., Purdue, 1988. Distributed systems, networking, user interfaces.

M. Wu, Visiting Assistant Professor, Mathematical Sciences; Ph.D., University of California, Irvine, 2012. Mathematical biology, modeling of living systems.

Z. Wu, Associate Professor, Mathematical Sciences; Ph.D., Yale University, 2009. Biostatistics, high-dimensional model selection, linear and generalized linear modeling, statistical genetics, bioinformatics.

V. Yakovlev, Research Associate, Mathematical Sciences; Ph.D., Institute of Radio Engineering and Electronics, Russian Academy of Sciences, 1991. Antennas for MW and MMW communications, electromagnetic fields in transmission lines and along media interfaces, control and optimization of electromagnetic and temperature fields in microwave thermal processing, issues in modeling of microwave heating, computational electromagnetics with neural networks, numerical methods, algorithms and CAD tools for RF, MW and MMW components and subsystems.

H. Zhang, Assistant Professor, Biomedical Engineering; Ph.D., Johns Hopkins University; Biomedical robotics, biomedical imaging, ultrasound and photoacoustic instrumentation, functional imaging of brain and cancer, image-guided therapy and intervention.

Program of Study

The Neuroscience program offers graduate studies toward the M.S. degree. This program is designed to provide students with a strong foundation in molecular, psychological, computational, quantitative and interdisciplinary approaches to neuroscience. Neuroscience is a critical and challenging area of human endeavor. Our faculty and students thrive from the synergy of our diverse approaches to understanding the brain and nervous system. The faculty involved in the program have a strong record of extramural funding and provide an excellent research-oriented environment. As a 'Program' in Neuroscience, faculty from departments across campus train our students and collaborate on research and projects. The program comprises four broadly defined areas:

- *Cellular and Molecular Neuroscience*: Training in neurophysiological methods such as electrophysiology, optogenetics, molecular biology, genetics, biochemistry and biophysics, appropriate to topics in neurobiology.
- *Systems Neuroscience*: Training in structure-function relationship of neural networks, neural substrates of learning and memory, psychopharmacology of nervous system disorders including Alzheimer's disease.
- *Computational Neuroscience*: Training in the use of experimental and theoretical methods for the analysis of brain function.
- *Psychological Science*: Training in how the brain and nervous system interact with development, mental health, cognition, social processes, and behavior.

Master of Science in Neuroscience

Goals:

1) Prepare future professional students and industry leaders in the field of neuroscience so that they are ready to help solve the world's most challenging problems affecting the brain.
2) Create a comprehensive educational interdisciplinary program in neuroscience at WPI that distinguishes our program from others typically offered at the master's level due to the focus on both basic and translational neuroscience coupled with a strong computational base and links to industry partners.
3) Development of research areas linking neuroscience to areas like data science and biomedical engineering, in order to train students in a multidisciplinary approach.

Admissions Requirements

Students applying to the M.S. Degree program in Neuroscience are expected to have a bachelor's degree in biology, biochemistry, computer science, mathematics, psychology, neuroscience, or a related field, and to have taken introductory courses in a neuroscience-related field such as biology, biochemistry, computer science, mathematics and/or psychology. For example, a student with a bachelor's degree in biology is expected to have also completed courses in calculus and statistics prior to submitting an application. A strong applicant who is missing background coursework as needed for course requirements may be admitted, with the expectation that he or she will take and pass one or more undergraduate courses in this area of deficiency either during the summer prior to admission or within the first semester after admission. These remedial courses will not count towards meeting the M.S. degree requirements. The determination of what course or courses will satisfy this provision will be made by the Neuroscience Faculty Steering Committee, which consists of faculty members from the participating departments at WPI. Students who are not WPI undergraduates or graduates will be required to submit GRE/TOEFL scores.

Degree Requirements

For the M.S.

Students pursuing the M.S. degree in Neuroscience must complete a minimum of 31 credits of relevant work at the graduate level. The M.S. degree requirements have been designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively, and students who plan to pursue a PhD degree later.

Matriculated students will be assigned an academic advisor from the neuroscience program. In consultation with the academic advisor, the student will prepare a Plan of Study outlining the selections that will satisfy the M.S. degree requirements. This Plan of Study must then be approved by the Program's Review Committee, which consists of faculty members from each of the participating departments.

Core Neuroscience Coursework Requirements (Minimum of 19 Credits)

A student in the M.S. program must take courses to satisfy each of the following requirements:

Requirements Minimum Credits

1. At least three Neuroscience courses (Note 1) 9
2. At least one Biology courses (Note 2) 3
3. At least one Computer Science course (Note 2) 3
4. One Bioethics course (Note 3) 1
5. One Scientific Writing or Experimental Design course (Note 4) 3

NOTES

1. Chosen from the list of graduate NEU courses.
2. Chosen from the corresponding lists of Program Elective Courses below
3. For example, BB 551 Research Integrity in the Sciences or ID 500 Responsible Conduct of Research
4. For example, BB 553 Experimental Design and Statistics in the Life Sciences, MA 546 Design and Analysis of Experiments. Courses such as ID 527 Fundamentals of Scientific Teaching and Pedagogy are currently offered for no credit and will be considered for meeting this requirement at which time they are offered to students for credit.

In addition to the 19 credits in the Core Neuroscience Coursework Requirement, M.S. students must complete either the Thesis Option or the Non-thesis Option described below. Students supported with a Teaching Assistantship, Research Assistantship or Fellowship for more than one academic year are required to do the Thesis Option.

M.S. Thesis Option

Students in the M.S. thesis option must complete a 9-credit thesis. Students interested in research, and in particular those who are considering pursuing a Ph.D. degree in Neuroscience or a related area, are strongly encouraged to select the M.S. thesis option. The thesis must be advised or co-advised by a faculty member affiliated with the Neuroscience Program. If the advisor is not a tenure-track faculty at WPI, then a Neuroscience affiliated tenure-track faculty must serve as the thesis co-advisor. A thesis proposal must be submitted to and approved by the student's advisor(s) and the Neuroscience Faculty Steering Committee before the student can register for more than three thesis credits. Upon approval of the thesis proposal, the Steering Committee will appoint a thesis reader, who should be a faculty member affiliated with the Neuroscience program from a department different to that (those) of the thesis advisor(s). The thesis reader will serve as an examiner for the student's thesis. The student then must satisfactorily complete a written thesis that is approved by the thesis advisor(s) and the thesis reader, and present the thesis results to the Neuroscience faculty in a public presentation.

Non-Thesis Option

Students in the M.S. non-thesis option must complete the remainder of the 31 credits required for the M.S. degree using one or both of the following choices:

- **A 3-6 credit research or practice-oriented internship**. All non-thesis students are strongly encouraged to pursue this choice. The internship is to be carried out in cooperation with a sponsoring organization or affiliated research lab, and must be approved and overseen by a faculty member affiliated with the Neuroscience Program. The faculty member is responsible for supervising the internship and ensuring that the internship has sufficient rigor and content for graduate-level neuroscience work. Internships will often focus on applied projects in an industry setting, although internships could also be completed in a research lab. Students will produce a written report at the conclusion of the internship. The format for the report—which is significantly shorter and less formal than a thesis—will be determined by the student's advisor. Students will also be encouraged to present their work to the Neuroscience faculty in a public presentation.
- **Additional Program Elective Courses**. Elective courses must include one Neuroscience course (in addition to the three Neuroscience courses in the Core Neuroscience Requirements) and any additional graduate courses on the list of Program Elective Courses below.

Program Elective Courses

Students in the Neuroscience M.S. program may take program electives, as needed, to satisfy the remainder of the 31-credit degree requirement, and to tailor their Neuroscience degree program to areas of personal interest. An elective can be any graduate course listed below, although students are expected to select electives to produce a consistent program of study. Other graduate courses, graduate research credits, or ISGs not on this list may be used with prior approval of the Faculty Steering Committee, and if consistent with the student's Plan of Study.

List of Elective Courses:

Relevant Neuroscience courses:

- NEU 501 Neuroscience
- NEU 502 Neural Plasticity
- NEU 503 Computational Neuroscience
- NEU 504 Advanced Psychophysiology
- NEU 505 Brain-Computer Interaction

Relevant Bioinformatics and Computational Biology courses:

- BCB 501/BBT 581 Bioinformatics
- BCB 502/CS 582 Bio visualization
- BCB 503/CS 583 Biological and Biomedical Database Mining
- BCB 504/MA 584 Statistical Methods in Genetics and Bioinformatics
- BCB 510 Bioinformatics and Computational Biology Seminar

Relevant Biology and Biotechnology courses:

- BBT 561 Model Systems: Experimental Approaches and Applications
- BBT 581/ BCB 501 Bioinformatics
- BB570/CH 555 Cell Signaling

Relevant Biomedical Engineering courses:

- BME 550 Tissue Engineering
- BME 555 BioMEMS and Tissue Micro engineering
- BME 560 Physiology for Engineers
- BME 583 Biomedical Microscopy and Quantitative Imaging

Relevant Chemistry and Biochemistry courses:

- CH 538 Medicinal Chemistry
- CH 541 Membrane Biophysics
- CH 555D Drug and Regulations
- CH 555R Drug Safety and Regulatory Compliance
- CH 555/PH597 Cell Mechanics
- CH 555/BB570 Cell Signaling

Relevant Computer Science courses:

- CS 5007 Introduction to Applications of Computer Science with Data Structures and Algorithms
- CS 5084 Introduction to Algorithms: Design and Analysis 84
- CS 528 Mobile and Ubiquitous Computing
- CS 534 Artificial Intelligence
- CS 539 Machine Learning
- CS 541/DS 541 Deep Learning
- CS 542 Database Management Systems
- CS 546 Human-Computer Interaction
- CS 548 Knowledge Discovery and Data Mining
- CS/RBE 549 Computer Vision
- CS/SEME 565 User Modeling
- CS/SEME 566 Graphical Models for Reasoning under Uncertainty
- CS/SEME 567 Empirical Methods for Human-Centered Computing
- CS 573 Data Visualization
- CS 584 Algorithms: Design and Analysis
- CS 585/DS 503 Big Data Management
- CS 586/DS 504 Big data Analytics

Relevant Data Science courses:

- DS 501 Introduction to Data Science
- DS 502/MA 543 Statistical Methods for Data Science

Relevant Mathematical Sciences courses:

- MA 508 Mathematical Modeling
- MA 543/DS 502 Statistical Methods for Data Science
- MA 510/CS 522 Numerical Methods
- MA 511 Applied Statistics for Engineering and Scientists
- MA 542 Regression Analysis
- MA 546 Design and Analysis of Experiments
- MA 550 Time Series Analysis
- MA 556 Applied Bayesian Statistics

Course Descriptions

All courses are 3 credits unless otherwise noted.

NEU 501. Neuroscience

In this course, students will develop an understanding of neurobiology at several levels, from the physiology of individual neurons, through the functioning of neural circuits, and finally to the behavior of neural systems such as vision, motion, and memory. Topics covered include spatial orientation and sensory guidance, neuronal control of motor output, neuronal processing of sensory information, sensorimotor integration, neuromodulation, circadian rhythms and cellular mechanisms of learning and memory. Furthermore, students will learn about artificial intelligence and machine learning approaches to creating computational models of the brain using artificial neural networks and deep learning. The class will be based on lectures accompanied by in-class activities and will include weekly discussion of papers from the scientific literature. The class will focus on a guiding theme, such as neurotransmitter systems, with emphasis on research of human neurological problems, such as schizophrenia, addiction, and neurodegenerative disorders.

NEU 502. Neural Plasticity

Neuronal connections strengthen and weaken with learning, memory, or other events; a phenomenon called synaptic plasticity. In this course, we explore the underlying biological, biophysical and biochemical changes responsible for plasticity. This course covers the structure and organization of neuronal connections, the neurotransmitter receptors that line these structures, the signaling pathways that are mediated in synapses, the mechanical processes that underlie protraction and retraction, and the pharmacological agents that stimulate or block these changes. Students are required to have had an undergraduate level course in biology and biochemistry.

NEU 503. Computational Neuroscience

Computational neuroscience explores the brain at many different levels, from single cell activity, to small local network computation, to the dynamics of large neuronal populations across the brain. This course will introduce students to a multifaceted array of approaches that span biology, physics, mathematics and computer science as well as facilitate the integration of modeling (on both the single molecule and neuron level) and quantitative techniques to investigate neural activity at these different levels. Where possible, this course has a tripartite organization. First, the theory is presented from a text or journal article. Second, students read and critique a paper that uses the technique. Finally, simulations and/or problem sets are assigned to fix the knowledge learned in the course. Pertinent examples will be drawn from research done by WPI students and faculty.

NEU 504. Advanced Psychophysiology

This course will provide an in-depth understanding of what psychophysiology is and the common methods used to understand psychophysiological responses. Common psychophysiological methods will be discussed in-depth, such as sympathetic and parasympathetic nervous system, facial electromyography, electroencephalography (EEG), respiration, blood pressure, pulse rate, skin temperature, electrodermal responses, cortisol, and other neuroendocrine monitoring methods. The social, cognitive, emotional, and motivational responses to different psychological events will be explored in detail. Computational methods will be described from the fields of artificial intelligence, machine learning, and mobile computing for capturing, processing and discovering patterns in physiological and behavioral data. In addition, the course will examine how biofeedback works in educational, clinical, and experimental settings. Students may not receive credit for both PSY 2502 and NEU 504.

NEU 505. Brain-Computer Interaction

This course will explore the current state of brain sensing and its application to human-computer interaction research. This course covers brain function, sensing technology, machine learning methods, and applications of brain-computer interfaces in various domains. This course aims for students to (1) obtain the background to conduct research in brain-computer interaction and human-computer interaction; (2) understand the literature in the field of brain sensing for human-computer interaction research; (2) understand the various tools used in brain sensing, with a focus on functional near-infrared spectroscopy (fNIRS) research; (3) understand the steps required to use real-time brain sensing data as input to an interactive system; (4) understand the domains and contexts in which brain-computer interfaces may be effective; (5) understand the open questions and challenges in brain-computer interaction research today.

Return to Table of Contents

Faculty

D.T. Petkie, Department Head and Professor; Ph.D., Ohio State University. Millimeter-wave and Terahertz sensing, spectroscopy, electromagnetic scattering and propagation, photonics, optics and imaging.

P. K. Aravind, Professor; Ph.D., Northwestern University. Quantum information theory.

N. A. Burnham, Professor; Ph.D., University of Colorado. Mechanical properties of nanostructures, instrumentation for nanomechanics.

G. S. Iannacchione, Professor; Ph.D., Kent State University. Soft condensed matter physics/ complex fluids, liquid-crystals, calorimetry, and order-disorder phenomena.

D. C. Medich, Associate Professor; Ph.D., University of Massachusetts – Lowell. Nuclear science and engineering, medical and health physics, radiation biology.

R. S. Quimby, Associate Professor; Ph.D., University of Wisconsin – Madison. Optical properties of solids, laser spectroscopy, fiber optics.

L. R. Ram-Mohan, Professor; Ph.D., Purdue University. Field theory, many body problems, solid state physics, and finite-element modeling of quantum systems.

I. Stroe, Associate Teaching Professor; Ph.D., Clark University. Experimental biophysics, protein structure, dynamic, and functionality.

L. V. Titova, Associate Professor; Ph.D., University of Notre Dame. THz spectroscopy of nanomaterials for energy applications; optical excitations and ultrafast carrier dynamics in nanomaterials.

R. Trubko, Assistant Professor; Ph.D., University of Arizona. Quantum physics, Nitrogen-vacancy centers in diamond, magnetic microscopy and imaging for biosciences and geosciences, machine learning, optics.

Q. Wen, Associate Professor, Ph.D., Brown University. Experimental biophysics, mechanical properties of tissue cells and biological materials, cell-ECM interactions.

K. Wu, Assistant Professor, Ph.D., New York University. Active matter, kinesin-driven microtubules, fluid dynamics, experimental soft matter and biophysics.

R. Zekavat, Professor; Ph.D., Colorado state University. Wireless Localization and Communications, Propagation Channel Modeling, Statistical Signal Processing, Sensor Data Analysis and Machine Learning.

A. Zozulya, Professor; Ph.D., Lebedev Physics Institute. Nonlinear optics, photorefractive materials, atom pipes.

Affiliated Faculty

C. Furlong, Professor; Ph.D., WPI, 1999. MEMS and MOEMS, micro- /nano-technology & -fabrication, mechatronics, laser metrology & applications, holographic and ultrasonic imaging and NDT, computer modeling of dynamic systems, acoustics.

Y. Liu, Associate Professor; Ph.D., University of Maryland, 2011. Fiber optical tweezers, silicon nanophotonics and nanomechanics, optofluidics, fiber optic sensors, cell mechanics, biomimetics.

Research Areas

The two major areas of research in the department are: Biophysics/Soft-Matter and Nanoscience/Condensed Matter Physics, including optics and photonics.

Nanoscience/Condensed Matter

Cold atoms – Bose-Einstein Condensation of bosons and fermions, atom wave guides and interferometers.

Magnetic Solids – Magnetic impurities in semiconductors: diluted magnetic semiconductors and the onset of ferromagnetism in spintronic materials.

Nanomechanics – Mechanical properties of nanostructures, instrumentation and metrology for nanomechanics.

Photonics – Nonlinear optics, fiber optics, optical properties of rough surfaces and of thin metal films. Development of infrared fiber lasers and materials, mid-IR and FIR quantum cascade laser design and Photonic Integrated Circuits.

Quantum Information – Foundations of quantum mechanics, quantum algorithms.

Semiconductors – Optical properties of super-lattices, heterostructure laser design, spintronics in diluted magnetic semiconductors,devices.

Spectroscopy – Laser spectroscopy of impurity ions in glasses, quasi-elastic/ inelastic light scattering and excitation/ modulation spectroscopy of super-lattices, thin films, surface phenomena and gas phase molecular spectroscopy.

Ultrafast optical spectroscopy – Terahertz science and technology, optical properties of nanomaterials for energy conversion.

Wavefunction Engineering – Nanostructures, finite-element modeling of quantum systems and wells, field theory.

Biophysics/Soft-Matter

Active matter – non-equilibrium statistical physics, dynamics of confined active fluids, self-organization of energy-consuming materials, self-propelled particles, self-pumping fluids, biopolymers (microtubules, actins), molecular motors (kinesin, myosin), bio-mimetic materials.

Biomaterials – hydration effects on protein dynamics, thermodynamics of proteins and DNA, self-assembly of biomaterials, dielectric relaxation spectroscopy, relaxation calorimetry, resonant ultrasound spectroscopy, studies of tissue cells, theory and simulations of bio-polymers and molecular motors.

Biomechanics – Locomotion of living organisms, cellular structure and motion, computational biophysical fluid dynamics.

Cellular biophysics – Cell mechanics and intra-cellular transport, physics of the cytoskeleton (cellular skeleton), cargo transport in cells, super-resolution imaging, correlation spectroscopy, simulations of cellular processes.

Return to Table of Contents

Complex Fluids – Diffusion and transport properties of complex fluids, light scattering spectroscopy of liquids and polymer melts, mesoscale simulations of liquids, capillary wave theory, theory and simulations of phase transitions in multi-component mixtures, active fluids.

Glasses – Theory and simulation, thermodynamics and relaxation dynamics.

Liquid Crystals – Thermotropic/ lyotropic/ colloidal systems, phase transitions and critical phenomena, cooperative behavior and self-assembly, quenched random disorder effects, calorimetry instrumentation.

Polymers – Molecular properties at the single molecule level, polymer and bio-macromolecular solutions, surfactants, colloids.

Program of Study

The Department of Physics offers programs leading to the M.S. and Ph.D. degrees in Physics and the M.S. and Ph.D. degrees in Applied Physics with concentrations in Biophysics and Soft Condensed Matter, Medical Physics, Nanoscience and Technology, Photonics, and Radiological Sciences. The Department of Physics also offers a Master of Science program in Physics for Educators (MPED) and a Graduate Certificate in Nuclear Science and Engineering (NSE) and an accelerated B.S./M.S. program.

Research opportunities are available in experimental, theoretical, and computational studies of biophysics and soft condensed matter physics, materials science, medical physics, nanoscience, optics, photonics, atomic physics, and radiological sciences. In addition to coursework and research opportunities, professional development opportunities also exist for students interested in a career pathway in academia, industry, federal laboratories, and education. The Physics program reserves its financial aid for graduate students in the Ph.D. program.

Physics Program (Ph.D. and M.S.)

WPI Physics graduate program provides students with a broad background in the core areas of fundamental physical sciences and prepares students for careers in research in an academic, industry, or national laboratory setting. In addition to core courses, students are encouraged to acquire breadth by choosing special topics courses to complement their studies. Students carry out rigorous research in theoretical and experimental physics areas including: biophysics, condensed matter physics, optics, quantum physics, atomic, and nuclear physics. The M.S. program provides a suitable foundation for the pursuit of a Ph.D. degree in physics, or a related field, or for a career in industry immediately after graduation.

Applied Physics Program (Ph.D. and M.S.)

The Applied Physics program provides a flexible set of interdisciplinary skills to prepare students for careers at national and international laboratories, industry, education, and academia. It combines a core physics curriculum with cross-cutting research in areas at interface of physics and other scientific disciplines. Applied Physics Ph.D. and M.S. students are required to select a research concentration and a corresponding set of thematically related courses from the following five options: Biophysics and Soft Condensed Matter Physics, Medical Physics, Nanoscience and Technology, Photonics, and Radiological Sciences.

Master of Science in Physics for Educators (MPED)

The Master of Science in Physics for Educators is designed specifically for middle school, high school, and community college in-service educators. The emphasis of the program is put on physics courses designed for educators and is combined with courses in assessment and evaluation theory and a participant-designed project. The physics content courses are intended to give educators a deep but applicable understanding of physics that makes advanced physics topics easily accessible to educators and the students they teach. Topics covered will include modern physics, methods in physics and physics for citizens and leaders. Support for degree candidates extends beyond the specific coursework and projects as participants will become part of a network of physicists which ranges from local individuals to a much broader community. The program may be used to help middle and high school educators move from Initial to Professional Licensure in Massachusetts. For information about admissions and requirements, see the listing under STEM for Educators.

Graduate Certificate in Nuclear Science and Engineering (NSE)

The Graduate Certificate in Nuclear Science & Engineering requires the successful completion of 12-18 graduate credit-hours) with an overall GPA of 3.0. Credits are chosen from the NSE 510-50 course listing or by approval of the NSE Program Committee. Courses cover such topics as nuclear power, radioactivity, chain reaction physics, nuclear reactor safety, power plant design and operation, and case studies of nuclear accidents. These courses are offered on campus, and online through Corporate and Professional Education. The faculty in the certificate program hold a full-time position in a WPI academic department or are affiliated faculty approved by an academic department and NSE program review committee.

Combined B.S./M.S. Program

The Department of Physics offers a combined B.S./M.S. degree option in Physics and Applied Physics for undergraduate students currently enrolled at WPI. The university rules for B.S./M.S. programs are described in the undergraduate catalog and graduate catalog. It is recommended that the M.S. application be submitted at the beginning of the student's junior year of undergraduate study at WPI.

Admission Requirements

M.S. and Ph.D. Physics and Applied Physics Programs

For the M.S. or Ph.D. in Physics programs, a B.S. in Physics, Applied Physics or the equivalent is required for admission. The Applied Physics M.S. and Ph.D. programs also allow students to be admitted with B.S. degrees from other areas, such as engineering, materials science, or other natural sciences. Candidates not meeting this minimum academic requirement may be required to take additional undergraduate courses, which do not count towards coursework to satisfy graduate degree requirements. Well-qualified Ph.D. candidates entering with an M.S. degree in Physics, Applied Physics or its equivalent will be considered by the Physics Department Graduate Committee (PDGC) for admission with Ph.D. 60 status, as described in Degree Requirements section under General Requirements for the Doctorate. The application to any program must include a Statement of Purpose describing the motivation for pursuing a graduate degree in Physics or Applied Physics at WPI and identifying one or more faculty members as potential research advisors. Students applying to the Applied Physics program are required to identify a specific concentration. Applicants should contact faculty directly to learn about their research. Transcripts from every previously attended college or university, a CV, and three letters of reference are also required.

MPED and NSE Programs

A B.S. in Physics is preferred. However, applicants with comparable backgrounds will also be considered.

Degree Requirements

For the M.S.

The M.S. degree in Physics or Applied Physics requires completing 30 graduate credit-hours; applicants must specify their intention to pursue either a thesis or non-thesis option. All full-time students are required to register for the zero-credit graduate seminar (PH 580) each term. The thesis option requires a minimum of 15 credit-hours of coursework as described below, a minimum of 6 hours of thesis research (PH 599) and the completion, public seminar presentation, and defense of an M.S. thesis. The thesis option will require that a thesis committee be formed one year prior to the student's expected graduation date. This committee will be formed by the student and his/her research advisor and will consist of three faculty members (including the advisor, who will be responsible for providing mentoring to the student and for overseeing the progress of the student towards a successful completion of their degree). The research advisor may not be the chair of this committee.

Alternatively, students may pursue a non-thesis option which requires the student to complete a minimum of 24 credit-hours of graduate coursework from the courses listed below, and a minimum of 6 hours of directed research (PH 598). Specific course requirements for the M.S. in Physics or Applied Physics are as follows:

- M.S. in Physics: 15 credits are required in core courses (PH 511, PH 514, PH 515, PH 522, and PH 533). The remaining 15 credits are electives, thesis research, or directed research; courses taken outside of the department must be approved by the PDGC.
- The M.S. in Applied Physics:
  - Biophysics/Soft Condensed Matter Concentration: Required Core Courses: PH 511, PH 522; PH 562. Students are also required to complete additional coursework (minimum of 6 credit hours for thesis option and a minimum of 15 credit hours for non-thesis option) in elective courses: PH 563, PH 533, PH 514, PH 541, PH 554, PH 561, PH 571, BME 555, BME 564, BME 583, CHE 541 or other courses approved by PDGC.
  - Medical Physics Concentration: Two of the core physics courses (PH 511, PH 514, PH 515, PH 522, and PH 533), NSE 515, NSE 530, NSE 560, NSE 570, NSE 580, NSE 585, an undergraduate or graduate Anatomy and Physiology course.
  - Nanoscience and Technology Concentration: Required Core Course: PH 514, and PH 511 or PH 533. Students are also required to complete additional coursework (minimum of 9 credit hours for thesis option and a minimum of 18 credit hours for non-thesis option) in elective courses: PH 511 or PH 533, PH 515, PH 522, PH 541, PH 554, PH 561, MTE 575, MTE 509, MTE 532, CH 516, CH 554, or other courses approved by the PDGC.
  - Photonics Concentration: Required Core Courses: PH 514, PH 533, PH 544. Students are also required to complete additional coursework (minimum of 6 credit hours for thesis option and a minimum of 15 credit hours for non-thesis option) in elective courses: PH 511, PH 515, PH 541, PH 548, PH 554, PH 561, PH 571, ME 5225, ME 5301, BME 583 or other courses approved by PDGC.
  - Radiological Sciences Concentration: Required Courses: Two of the core physics courses (PH 511, PH 514, PH 515, PH 522, and PH 533), NSE 515, NSE 530, NSE 560. Students who are pursuing non-thesis option are required to complete a minimum of 9 credit-hours of PH or NSE graduate courses or other courses approved by the PDGC.

Changing of M.S. Option:

Students may petition the PDGC to switch from a non-thesis to a thesis option. Such petition must include justification, and a letter of support from a potential M.S. thesis advisor. Students may also petition PDGC for switching from a thesis to a non-thesis option, switching between Physics and Applied Physics programs, and changes in Applied Physics concentration. Petitions will be reviewed in consultation with student's advisor, when appropriate.

For the Master of Science in Physics for Educators (MPED)

For a complete overview of degree requirements, please see STEM for Educators section starting on page 191.

For the Ph.D in Physics and Applied Physics.

Students in the Physics or Applied Physics Ph.D. program are required to complete 90 graduate credit hours of coursework and a minimum of 30 credits of research (Directed Research, PH 598 or Ph.D. Dissertation, PH 699). These students also must complete and defend their Ph.D. thesis. Courses taken to satisfy M.S. degree requirements will be counted toward the Ph.D. credit requirements, but completion of an M.S. degree is not required. All full-time students are required to register for the zero-credit graduate seminar (PH 580) each term.

Students entering the Physics or Applied Physics Ph.D. program who already have been granted an M.S. degree in Physics, Applied Physics, or Engineering Physics may be promoted to Ph.D. 60 status. Ph.D. 60 students are required to complete 60 graduate credit hours, including a minimum of 30 credits of research (Directed Research, PH 598 or Ph.D. Dissertation, PH 699). Coursework requirements for the students in Ph.D. 60 status will be determined by the PDGC upon review of student's previous graduate coursework.

The PDGC reviews each student's academic work on an annual basis, and the committee and the academic or research advisor may require additional coursework to address specific deficiencies in the student's background. Students must maintain a minimum of a 3.0 GPA to be in good standing. One year of residency in the program is required.

A description of other Ph.D. program requirements follows below.

Comprehensive Written Examination

Students entering the Ph.D. program in Physics or Applied Physics are required register for and pass the *Comprehensive Written Examination* (PH 798) no later than the end of their second year. No more than 3 attempts to pass this exam are allowed. This exam is offered twice a year during Fall and Spring semesters. The exam consists of four areas depending on the degree program, as follows:

- Ph.D. in Physics: Classical Mechanics; Quantum Mechanics; Electrodynamics; Thermodynamics and Statistical Physics
- Ph.D. in Applied Physics:
  - Biophysics and Soft Condensed Matter Concentration: Classical mechanics; Statistical Mechanics; Biophysics and Soft Condensed Matter; and an additional area chosen in consultation with the student's thesis committee and approved by PDGC (examples: Microscopy and Imaging, Computational Biophysics, AFM)
  - Medical Physics Concentration: Radiation Biology, Health Physics, Diagnostic Medical Physics, Radiation Therapy Physics.
  - Nanoscience and Technology Concentration: Quantum Mechanics; Classical Mechanics or Electrodynamics, and two additional areas such as another core Physics area, Solid State Physics, Atomic Force Microscopy, Nanomaterials, Spectroscopy, or an alternative topic chosen in consultation with the student's thesis committee and approved by PDGC
  - Photonics Concentration: Quantum Mechanics; Electrodynamics; Photonics, and additional area chosen in consultation with the student's thesis committee and approved by PDGC
  - Radiological Sciences Concentration: Nuclear Instrumentation, Health Physics, Radiation Biology and a core physics area chosen in consultation with the student's thesis committee and approved by the PDGC

Ph.D. Qualifying Examination

Students enrolled in the Physics or Applied Physics Ph.D. program are required to register and pass, no later than the end of the third year after formal admittance to the Ph.D. program, the *Ph.D. Qualifying Exam* (PH 799). Here, the student is required to write and defend an original research proposal before a committee representative of the area of their specialization, approved and appointed by the PDGC. The students are allowed only two attempts to pass this exam. The examination is used to evaluate the ability of the student to pose meaningful scientific questions, to propose experimental or theoretical methods for answering those questions, and to interpret the validity and significance of probable outcomes of these theoretical conjectures, models or experiments. The committee will consist of a minimum of three physics faculty members including the advisor, and at least one faculty member from outside the department, and will administer and evaluate the exam. The research advisor may not be the chair of this committee. The students are also required to take and pass a one-credit scientific writing course (PH 585) prior to their first attempt at taking the Ph.D. Qualifying Exam.

Ph.D. Dissertation

To fulfill the final Ph.D. degree requirement, the candidate must submit and defend a satisfactory dissertation to the dissertation committee formed in consultation with the research advisor and approved by the PDGC. This committee will consist of a minimum of three physics faculty members including the advisor, and at least one faculty member from outside the department. The research advisor may not be the chair of this committee.

Transferring between Ph.D. program options:

Students may petition the PDGC to switch between a Physics and Applied Physics programs, or to change the concentration. Such petition must include justification, and a letter of support from student's advisor.

Course Descriptions

All courses are 3 credits unless otherwise noted.

Note: Students must maintain a minimum of a 3.0 GPA to be in good standing.

PH 500. Independent Study (ISG)
(credits are arranged: 1-3)
Various specialized topics and/or research areas from one to two graduate students. Arranged individually with the faculty.

PH 511. Classical Mechanics I
Lagrangian formulation Kinematics and dynamics of rigid bodies. Small oscillations. Motion in non-inertial frames, Hamiltonian mechanics. Canonical transformations. Hamilton-Jacobi theory.

Return to Table of Contents

PH 514. Quantum Mechanics I

Schrodinger equation, potential wells and barriers, Hilbert space formulation of quantum mechanics and applications, Central potentials, hydrogen atom, isotropic oscillator, angular momentum and spin.

PH 515. Quantum Mechanics II

Time independent perturbation theory, variational method and WKB method, time-dependent perturbation theory, partial wave theory of scattering, integral approach to scattering theory and Born approximation.

PH 522. Thermodynamics and Statistical Mechanics

The laws of thermodynamics. Elements of kinetic theory. Ensemble theory: canonical, microcanonical, and grand canonical ensembles. Quantum statistical mechanics, Bose-Einstein and Fermi-Dirac statistics. Special topics in statistical mechanics.

PH 533. Advanced Electromagnetic Theory

Classical electrodynamics including boundary-value problems using Green's functions, Maxwell's equations, electromagnetic properties of matter, wave propagation and radiation theory.

PH 541. Mathematical Methods in Physics.

The emphasis of the course is on mathematical techniques needed by physicists. The course covers functions of complex variable, special functions, Fourier and Laplace transforms, linear algebra and tensor analysis.

PH 544. Fundamentals of Photonics

Wave optics, Gaussian beams, photon optics, guided-wave optics, semiconductor optics (sources and detectors), interaction of photons with atoms.

PH 548. Fundamentals of Sensors

The course offers an overview of basic sensor physics and technologies to provide practical working knowledge of sensors. The course will include basic sensor operating principles, the physics of sensors, electrical interfacing to sensors, measurement principles, and applications. A wide range of sensors could be covered, such as temperature, photonic, acoustic, chemical, biological, electromagnetic, pressure, position and motion sensors. There will also be a laboratory component to the course.

PH 554. Solid State Physics

Phonons and specific heat of solids; electronic conductivity and band theory of solids; Fermi and Bose gases, Optical properties of materials. Magnetic interactions.

PH 561 Atomic Force Microscopy

Atomic force microscopes (AFMs) are instruments that allow three-dimensional imaging of surfaces with nanometer resolution and are important enabling tools for nanoscience and technology. The student who successfully completes this course will understand the functional principles of AFMs, be able to run one, and interpret the data that are collected. The recommended background for this course is a bachelor's degree in science or engineering. Students who have successfully completed PH 2510, the undergraduate version of this course, may not earn credit for PH 561.

PH 562. Fundamentals of Biological Physics

The course will cover the fundamental concepts of biological physics. The main objective is to learn how to apply the principles of physics, methods of mathematical analysis and computational modeling to complex biological systems and develop a better understanding. The approach will be truly interdisciplinary, bringing concepts from statistical physics, classical mechanics, cell biology, chemistry and biochemistry. Topics covered include: biology by the numbers: time and length scales, mechanical and chemical equilibrium in the living cell, entropy in biology, two-state systems and cooperative binding, random walks and the structure of macromolecules, architecture of the cytoskeleton, biological membranes, modeling of fluids, statistical view of biological dynamics, life in crowded environments, rate equations and dynamics in the cell, dynamics of molecular motors.

PH 563. Introduction to Experimental Methods in Biophysics

The course will overview the biophysical experimental techniques which are used in the study of the structure and function of biological systems at the cellular and molecular level. The main objectives are to understand the principles of most common biophysical technics and to learn essential skills to perform lab research in biophysics. Topics covered include: light microscopy, super-resolution microscopy, image processing, electron microscopy, x-ray diffraction and protein structure determination, NMR, spectroscopy, calcium measurements, resonance energy transfer, patch-clamp, optical tweezers, rheological characterization of soft materials, molecular force measurements, proportional-integral-derivative automation, protein expression, and design of DNA plasmid. Students will gain hands-on experience on cutting-edge biophysical techniques and will receive training on data collection, data analyzation, and scientific report writing.

PH 571. Biophysics / Soft Condensed Matter Journal Club

(1 credit)

Students interested in Biophysics / Soft Condensed Matter read journal articles, prepare presentations and give short talks, engage in critical discussion, and provide feedback to fellow students. The objectives of the course are for students to learn about current topics in the broad area Biophysics / Soft Condensed Matter and biotechnology and to improve their professional skills. Recommended background: A bachelor's degree in science, technology, engineering, or mathematics.

PH 572. Nanoscience Journal Club

(1 credit)

Students interested in nanoscience read journal articles, write abstracts, give short talks, engage in critical discussion, and provide feedback to fellow students. The objectives of the course are for students to learn about current topics in nanoscience and nanotechnology and to improve their professional skills.

PH 580. Graduate Seminar

(0 credits)

Students attend Physics Colloquia by WPI faculty and invited scientists on current research topics in different areas of physics. They discuss results and ideas presented in those talks. In addition, students give presentations on their research or on problems of current interest to physics community. The course therefore will provide opportunities for students to develop their presentation skills, broaden their perspectives and provide networking opportunities. All full-time physics graduate students are required to register and attend.

PH 585. Scientific Writing and Proposal Development

(1 credit)

This course will cover key elements of writing successful grant or fellowship proposals, as well as manuscripts. The topics that will be covered will include project development, identification of funding agencies or journals, proposal and manuscript writing and editing, as well as aspects of the submission and review process. Students will be expected to develop a proposal, and participate in reviews. Students are expected to complete this course prior to taking the Ph.D. Qualifying Exam in Physics. Recommended background: A bachelor's degree in science, technology, engineering, or mathematics.

PH 597. Special Topics

(1-3 credits)

Arranged by physics faculty for individual or groups of students, these offerings cover topics that are not covered by the regular Physics course offerings. Exact course descriptions are posted by the faculty in advance of the offering.

PH 598. Directed Research

(credit varies)

A directed and coherent program of research that, in most cases, will eventually lead to thesis or dissertation research. This is also used for Directed Research Rotation (for 3 credit hours) for first year students who have not yet taken the Qualifying Examination in order to explore the available research opportunities.

PH 599. M.S. Thesis Research

(credit varies)

Each student will work under the supervision of a member of the department on the thesis research for their Master of Science in Physics degree. (Prerequisite: Consent of advisor)

PH 699. Ph.D. Dissertation
(credit varies, no more than 30 credits)
Can be taken any time after passing the Physics Qualifying Examination but required in the last semester for the writing and defending of the Ph.D. dissertation. (Prerequisite: Consent of advisor)

PH 798. Comprehensive Written Examination
(0 credit)
Comprehensive Written Examination prepared, administered and evaluated by the Physics Department Graduate Committee (PDGC). Recommended background: Student should be enrolled in the Physics or Applied Physics Ph.D. program.

PH 799. Ph.D. Qualifying Examination
(0 credit)
Students are required to write and defend an original research proposal before a committee representative of the area of their specialization, approved and appointed by the Physics Department Graduate Committee (PDGC). Recommended background: Student should be enrolled in the Physics Graduate program, seeking a Ph.D. degree.

MPE 510. Classical Mechanics
(2 credits)
Broad coverage emphasizing interconnections of a mechanical description of the universe utilizing both algebraic and calculus language at a level appropriate for secondary school educators. Topics include: vectors and vector manipulation to describe motion, Newton's laws of motion; work and energy concepts; energy and momentum conservation laws; models of forces and interactions; generalized coordinates and momentum; overview of Lagrangian and Hamiltonian formulations.

MPE 520. Electrodynamics
(2 credits)
Broad coverage at the appropriate level emphasizing interconnections of the electromagnetic interactions in the universe utilizing both algebraic and calculus language at a level appropriate for secondary school educators. Topics include: electro and magnetostatics and dynamics, boundary-value problems; Maxwell's equations; overview of electromagnetic properties of matter and wave propagation (radiation).

MPE 530. Modern Physics
(2 credits)
Broad coverage of the three central areas of modern physics that emphasize the wonder and interconnections at the conceptual level appropriate for secondary school educators. Topics include: Quantum Physics (postulates, Schrödinger and Dirac formalisms, implications and interpretations), Special and Introduction to General Relativity (the four-vector, space-time, invariants, time dilation and length contraction), and Thermo/Statistical Physics (macroscopic variables, equation of state, state functions, response functions, microscopic variables, statistical approach, ensembles, the partition function).

MPE 540. Differential Equations in Nature
(2 credits)
Emphasizes connections and interconnections with the mechanical, electromagnetic, and modern areas as well as mathematical areas of oscillations, waves, and optics utilizing differential equations at a level appropriate for secondary school educators. Topics include: Free, damped, and driven-damped oscillations, waves, Doppler Effect, optics, interference and diffraction. Examples are drawn from a wide range of physical phenomena to illustrate each concept. To develop this content, homogeneous and non-homogeneous differential equations of the first and second order will be employed. Thick contextual meaning will be drawn to support mathematical foundation and vice versa to allow for deeper "authentic" learning.

MPE 550. Computational Methods in Physics
(2 credits)
Topics are chosen to illustrate various numerical techniques useful for educators and students to illustrate physics concepts and develop a sense of physical intuition through simulations and modeling. It is not intended to be a course on numerical methods; rather it will be aimed at the application of numerical methods to physical models. Various programming languages/platforms are utilized in each example to highlight the general nature and to provide choices matching students programming backgrounds.

MPE 560. Experimental Methods in Physics
(2 credits)
Hands-on methods of physically testing concepts and models of the universe. Technology is utilized but general methods accessible to barely outfitted lab environments are stressed. Topics covered are in a series of subject units, the physical principles underlying the phenomena to be observed and the basis for the measurement techniques employed is reviewed. Principles and uses of standard laboratory instruments (oscilloscopes, meters for frequency, time, electrical and other quantities, lock-in amplifiers, etc.) are stressed. In addition to systematic measurement procedures and data recording, strong emphasis is placed on processing of the data, preparation and interpretation of graphical presentations, and analysis of precision and accuracy, including determination and interpretation of best value, measures of error and uncertainty, linear best fit to data, and identification of systematic and random errors. Preparation of high-quality experiment reports is also emphasized. Representative experiment subjects are: mechanical motions and vibrations; free and driven electrical oscillations; electric fields and potential; magnetic materials and fields; electron beam dynamics; optics; diffraction-grating spectroscopy; radioactive decay and nuclear energy measurements.

MPE 572. Physics Research Experience for Teachers
(3 credits)
Provides educators with hands-on research experience either in the research programs in Physics at WPI or other venues but under the oversight of the physics faculty. The goal is to support the active involvement of educators in research in order to translate their research experience into new classroom activities and build long term collaborative relationships between the researcher(s), educator(s), and potentially the educator(s') students. Research activities can range from experimental to theoretical to computational and can involve multiple educators and/or their students with some expectation that the activity may lead to a publication.

MPE 574. Physics for Citizens and Leaders
(3 credits)
Emphasizes physics concepts and connections to society. Educators will explore and understand the important connections between society and the relevant physics concepts and their context. The goal is for the educator to be able to apply critical thinking of the application of physics to important societal issues. Topics can range from energy options, climate change, technology assessment and risk, ethical use of science.

MPE 576. Physics in Popular Culture
(3 credits)
Covers myths and misconceptions of physics in popular culture (i.e., movies, books, TV, web, etc.). The goal of this independent study is for the educator to be able to identify how the representation of physics in popular media perpetuates important myths and misconceptions that impact reasoning and critical thinking, sometimes in a profoundly negative way. Emphasis is placed on utilizing these representations as teaching/learning moments for the specific relevant physical concepts.

NSE 510. Introduction to Nuclear Science and Engineering
(3 credits)
This introductory course provides an overview of the field of nuclear science and engineering as it relates to nuclear power and nuclear technologies. Fundamental concepts relevant to nuclear systems are introduced, including radioactivity, radiation interaction phenomena, chain reaction physics, and transport in engineering materials. Nuclear reactor physics and design concepts are introduced with focus on light water fission reactors. A survey of advanced nuclear technologies and applications is provided. Prerequisites: graduate or senior standing or consent of the instructor.

NSE 515: Radiation Biology
(3 credits)
This course will introduce the student to fundamental concepts in radiation biology. Initially, theories will be developed concerning the effects of radiation exposure on basic biological systems, such as a virus or a cell. These theories will be based on our knowledge of radiation interaction mechanisms at the atomic/molecular level coupled with our knowledge of cell biology. Once developed, these theories will be compared against experimental observations and expanded to include cellular kinetic responses to radiation. Focus will then shift from the simple cell to more complex biological organisms. Ultimately, the student will be expected to appreciate the practical aspects and consequences of human radiation exposure and to properly apply this information in a radiation safety or medical physics environment.

NSE 520. Applied Nuclear Physics
(3 credits)
This course introduces engineering and science students to the fundamental topics of nuclear physics for applications, basic properties of the nucleus, nuclear radiations, and radiation interactions with matter. The course is divided into four main sections: (1) introduction to elementary quantum mechanics, (2) nuclear and atomic structure, (3) nuclear decays and radiation, and (4) nuclear matter interactions and nuclear reactions. Prerequisites: Physics of mechanics and electrodynamics (PH1110/11 and PH1120/21) and mathematical techniques up to and including ordinary differential equations (MA2051)

NSE 530. Health Physics
(3 credits)
This course builds on fundamental concepts introduced in NSE510 and applies them to key topics in health physics and radiation protection. Health physics topics include man-made and natural sources of radiation, dose, radiation biology, radiation measurement, and radiation safeguards. Radiation protection concepts are explored as they apply to existing and advanced nuclear power generators, including reactor safety, nuclear waste and byproducts, regulatory constraints, and accident case studies. Prerequisites: graduate standing or consent of the instructor

NSE 540. Nuclear Materials
(3 credits)
This course applies fundamental materials science concepts to effects on materials in harsh nuclear environments. An overview is provided on environments, special nuclear materials, and constraints in materials selection. Relationships are developed between nuclear effects on crystal structure, microstructure, degraded material performance, and bulk properties of engineering and electronic materials. Case studies provide examples of enhancements induced my multiple harsh environments and mitigation through material design hardening. Prerequisites: ES2001 or equivalent.

NSE 550. Reactor Design, Operations, and Safety
(3 credits)
This course provides a systems engineering view of commercial nuclear power plant technology. Power plant designs and their evolutions are studied, ranging from early to modern generation light water reactors, as well as advanced designs families, such alternate moderator and breeder reactors. Critical aspects of conventional power reactor designs are explored in detail, including steam supply, reactor core, control, and protection systems. Plant operational characteristics are studied, including reactor dynamics, control, feedback, and fuel cycle management. Critical power plant safety aspects of the design and operations are explored and reinforced with lessons learned from major power generator accident scenarios (including Three Mile Island, Chernobyl, and Fukushima Daiichi). Prerequisites: graduate standing or consent of the instructor

NSE 560: Nuclear Instrumentation
(3 credits)
Students will be introduced to the theory and operation of general nuclear instrumentation such as x-ray production and detection, gamma ray detection, Geiger counters, scintillators, photomultiplier detectors, and nuclear magnetic resonance. Hands-on activities and training are emphasized.

NSE 570: Diagnostic Medical Physics
(3 credits) (offered biennially)
Students will be introduced to the fields of diagnostic medical imaging with a focus on the fundamental imaging physics. Basic concepts, including: matter and energy, x-ray production, and photon interactions, will lead to topics in x-ray generation, nuclear magnetic resonance, and sound-wave propagation. The course will then focus on the different diagnostic imaging modalities including X-ray radiography, Computed Tomography, Nuclear Magnetic Resonance, Gamma Scintillation, and ultrasound imaging.

NSE 580: Radiation Therapy Physics
(3 credits) (offered biennially)
Students will learn the theory, practice, and application of radiation oncology and therapy. Using the basic concepts of matter and energy, the production of x-rays, and photon interactions in tissue, the student will be introduced to linear accelerator (LINAC) physics, radiation treatment planning, and photon and electron dosimetry. In addition, this course will cover topics of current interest in radiation therapy such as: intensity-modulated radiation therapy, calibration of electron and photon beams, brachytherapy, hyper-fractionation therapy, and charged particle therapy.

NSE 585: Medical Ethics and Responsible Conduct
(1 credit)
This material is intended to cover ethical issues in clinical medicine, scientific research, and in the professional conduct of the medical physicist. The term “ethics” is used here in the sense of a permissible standard of conduct for members of a profession.

NSE 595. Special Topics
(1-3 credits)
Arranged by faculty affiliate to the Nuclear Science and Engineering program for individual or groups of students, these courses survey areas that are not covered by the regular NSE course offerings. (Prerequisite: Consent of instructor.)

Return to Table of Contents

Robotics Engineering

Faculty

J. Xiao, Professor and Director; Ph.D., University of Michigan. Robotic manipulation and motion planning, artificial intelligence, haptics, multi-modal perception.

N. Bertozzi, Senior Instructor; M. S. Northeastern University. Engineering design graphics, active learning/flipped classrooms, program and course student outcomes assessment.

B. Calli, Assistant Professor, Ph.D., Delft University of Technology, 2015. Robotic manipulation, robot vision, machine learning, dexterous manipulation, environmental robotics.

L. Fichera, Assistant Professor; Ph.D., University of Genoa/Italian Institute of Technology. Continuum robotics, medical robotics, surgical robotics, image-guided surgery, laser-based surgery, medical devices

G. S. Fischer, Professor, Ph.D., Johns Hopkins University. Medical cyber-physical systems, surgical robotics, image-guided interventions, assistive technology, robot modeling and control, automation, sensors and actuators.

J. Fu, Assistant Professor; Ph.D., University of Delaware, 2013. Control theory, formal methods, machine learning.

M. A. Gennert, Professor; Sc. D., Massachusetts Institute of Technology 1987. Image processing, image understanding, artificial intelligence, robotics.

M.M.A. Hajiabadi, Assistant Teaching Professor, Ph.D., Worcester Polytechnic Institute (WPI), 2013. Soft Robotics, Legged Robotics

G. Lewin, Assistant Teaching Professor and Robotics Engineering Associate Director; Ph.D., University of Virginia, 2003. Systems integration, mobile robotics, mechatronics, sensors and control.

Z. Li, Assistant Professor; Ph.D., University of California, Santa Cruz, 2014. Human-robot interaction, Motion coordination of cyber-human system, Nursing and Rehabilitation Robots.

W. R. Michalson, Professor; Ph.D., Worcester Polytechnic Institute. Satellite navigation, real-time embedded computer systems, digital music and audio signal processing, simulation and system modeling.

M. Nemitz, Assistant Professor, Ph.D. The University of Edinburgh. Robotic soft materials, magnetism, fluidics, machine learning.

C. D. Onal, Associate Professor; Ph.D. Carnegie Mellon University, 2009. Soft robotics, printable robotics, origami-inspired robotics, bio-inspiration, control theory, human augmentation.

C. Pinciroli, Assistant Professor, PhD., Université Libre de Bruxelles, Belgium, 2014. Swarm robotics, software engineering, multi-agent systems, human- swarm interaction, programming languages.

M. B. Popovic, Assistant Research Professor; Ph.D. Boston University. Human neurosensory-motor organization, soft robotics, wearable robotics, assistive robotics, human augmentation systems.

C. B. Putnam, Senior Instructor, , M. S. Penn State University. Robotics systems design, industrial robotics.

X. Zeng, Assistant Professor; Ph.D., Ohio State University, 2016. Connected and automated vehicles, mobility cyber-physical systems, intelligent transportation systems, and optimal control.

H. Zhang, Assistant Professor; Ph.D., Johns Hopkins University, 2017. Biomedical robotics, biomedical imaging, ultrasound and photoacoustic instrumentation, functional imaging of brain and cancer, image-guided therapy and intervention.

Associated Faculty

E.O. Agu, Associate Professor; PhD., Massachusetts, 2001. Computer graphics, wireless networking, mobile computing and mobile health.

H. Ault, Associate Professor; PhD. Worcester Polytechnic Institute, 1988. Geometric modeling, mechanical design, CAD, kinematics, biomechanics and rehabilitation engineering.

S. Barton, Associate Professor; Ph.D. University of Virginia, 2012. Human-robot interaction in music composition and performance, design of robotic musical instruments, music perception and cognition, audio production.

C. A. Brown, Professor; Ph.D., University of Vermont, 1983. Surface metrology, machining, grinding, mechanics of skiing, axiomatic design.

R. J. Duckworth, Associate Professor, Ph.D., Nottingham University. Embedded computer system design, computer architecture, real-time systems, wireless instrumentation, rapid prototyping, logic synthesis.

C. Furlong, Professor; Ph.D., Worcester Polytechnic Institute. MEMS and MOEMS, micro-/nano-technology & -fabrication, mechatronics, laser metrology & applications, holographic and ultrasonic imaging and NDT, computer modeling of dynamic systems, acoustics.

G.R. Gaudette, William Smith Dean's Professor of BME; PhD. SUNY Stony Brook; Cardiac biomechanics, myocardial regeneration, biomaterial scaffolds, tissue engineering, stem cell applications, optical imaging techniques, cellular agriculture, crossing biological kingdoms.

X. Huang, Professor; Ph.D., Virginia Tech. Reconfigurable computing, VLSI integrated circuits, networked embedded systems

D. Korkin, Associate Professor, PhD., University of Illinois, Chicago, IL 2014. Data mining, social networks, machine learning, big data analytics.

Y.S. Liu, Assistant Professor; PhD. University of Maryland, 2011. Fiber optical tweezers, silicon nanophotonics and nanomechanics, optofluidics, fiber optic sensors, cell machanics, biomimetics.

P. Radhakrishnan, Assistant Teaching Professor; PhD., The University of Texas at Austin, 2014. Automated design and manufacturing; entertainment and medical engineering; optimization, machine learning and software development; kinematics, dynamics and design education.

Return to Table of Contents

C. L. Sidner, Research Professor; Ph.D., Massachusetts Institute of Technology, 1979. Discourse processing, collaboration, human-robot interaction, intelligent user interfaces, natural language processing, artificial intelligence.

J.Skorinko, Professor; Ph.D. University of Virginia, 2007. Social psychology, decision-making, interpersonal interactions.

E. Solovey, Assistant Professor, Ph.D., Tufts University, 2012. Human-computer interaction, user interface design, novel interaction modalities, human-autonomy collaboration, machine learning.

A. M. Wyglinski, Professor, Ph.D., McGill University. Wireless communication systems engineering, vehicular technology, cognitive radio, software-defined radio, autonomous vehicles, wireless spectrum, vehicular security, cyber-physical systems.

Y. Zheng, Assistant Professor; PhD., University of Michigan, 2016. Advanced and biomedical manufacturing, medical device design, tissue mechanics, biomedical machining process and modeling, catheter-based surgical devices, medical simulation, vascular ultrasound imaging, abrasive machining processes for biomedical and ceramic materials.

Program of Study

M.S. Program

The Robotics Engineering Department offers the M.S. degree with thesis and non-thesis (course-work only) options. The department strives to educate men and women to:

- Have a solid understanding of the fundamentals of Robotics Science, Engineering, and Systems.
- Have an awareness of the management and systems contexts within which robotic systems are engineered.
- Develop advanced knowledge in selected areas of robotics, culminating in a capstone research or design experience.

Admission Requirements

Students will be eligible for admission to the program if they have earned an undergraduate degree in Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering or a related field from an accredited university consistent with the WPI graduate catalog. Admission will also be open to qualified WPI students who opt for a five-year Bachelors-Masters program, with the undergraduate major in Computer Science, Electrical & Computer Engineering, Mechanical Engineering, Robotics Engineering or a related field. Admission decisions will be made by the Robotics Engineering Graduate Program Committee based on all of the factors presented in the application.

Degree Requirements

For the Graduate Certificate

The Graduate Certificate in Robotics Engineering includes the following requirements:

- Core (3 credits): RBE 500 |Foundations in Robotics
- Depth (9 credits): The 3 courses RBE 501 Robot Dynamics, RBE 502 Robot Control, and SYS 501 Concepts of Systems Engineering OR 9 credits of thematically-related RBE graduate-level coursework with RBE Graduate Program Committee approval.
- Elective (3 credits): Elective graduate coursework in Math, Science or Engineering with advisor approval

For the M.S.

The M.S. program in Robotics Engineering requires 30 credit hours of work. Students may select a non-thesis option, which requires a 3-credit capstone design/practicum, or a thesis option which requires a 9-credit thesis. All entering students must submit a plan of study identifying the courses to be taken and a prospective project topic before the end of the first semester in the program. The plan of study must be approved by the student's advisor and the RBE Graduate Program Committee, and must include the following minimum requirements:

1. **Robotics Core (15 credits)***
   - **Foundations (9 credits)**
     RBE 500 Foundations of Robotics
     RBE/ME 501 Robot Dynamics
     RBE 502 Robot Control
   - **Core (6 credits)**
     Any RBE 500+ other than the above.
     (*) *At least 15 credits are needed. Any additional credits accrued from these courses will be counted as Electives.*
2. **Engineering Context (3 credits):**
   3 credits hours selected from the following courses:
   ETR 500 Entrepreneurship and Innovation
   ETR 593 Technology Commercialization: Theory, Strategy and Practice
   MIS 576 Project Management
   OBC 506 The Heart of Leadership: Power, Reflection and Interpersonal Skills
   BUS 546 Managing Technological Innovation
   Courses prefixed by SYS at the 500 level or above.
3. **Capstone/Thesis (3-9 credits):**
   A 3 credit hour capstone experience or a 9 credit hour thesis.
4. **Electives (3-9 credits):**
   Sufficient course work selected from courses at the 500 level or above in Science, Engineering, or Business to total 30 credit hours with the approval of the student's advisor on the Plan of Study. Courses at the 4000 level may also be taken as electives in exceptional circumstances with the additional prior approval of the RBE Graduate Program Committee. The RBE 5900 (internship) course can be taken for maximum of 1 credit per semester and a maximum of 3 credits per degree.

Thesis Option

The M.S. thesis consists of 9 credit hours of work, normally spread over at least one academic year. A thesis committee will be set up during the first semester of thesis work. This committee will be selected by the student in consultation with the major advisor and will consist of the thesis advisor, who must be a full-time WPI RBE faculty member, and two other faculty members, at least one of whom is a WPI RBE faculty member, whose expertise will aid the student's research program. An oral presentation before the Thesis Committee and a general audience is required. In addition, all WPI thesis regulations must be followed.

Non-Thesis Options

As an alternative to a 9-credit research-based thesis, students may elect a 3-credit capstone from the following options:

- Capstone Project Experience in Robotics Engineering (RBE 594),
- Robotics Engineering Practicum (RBE 596), or
- Directed Research (RBE 598).

All of the non-thesis options must demonstrate significant graduate-level work involving Robotics Engineering, include substantial analysis and/or design, and conclude with a written report and public presentation.

Return to Table of Contents

The Capstone Project Experience in Robotics Engineering (RBE 594) is a project-based course that integrates theory and practice, and provides the opportunity to apply the skills and knowledge acquired in the Robotics Engineering curriculum. The project is normally conducted in teams of two to four students. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. The projects are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Robotics Engineering profession. The project must include substantial analysis and/or design, and conclude with a written report and public presentation.

The Robotics Engineering Practicum (RBE 596) provides students an opportunity to put into practice the principles that have been studied in previous courses. It will generally be conducted off campus and will involve a real-world robotics-engineering situation. Overall conduct of the practicum will be supervised by a WPI RBE faculty member; an on-site liaison will direct day-to-day activity. For a student from industry, the practicum may be sponsored by his or her employer. The project must include substantial analysis and/or design related to robotics engineering and will conclude with a public presentation and substantial written report submitted to the advisor and on-site liaison.

The Directed Research (RBE 598) option provides a research-oriented means to satisfy the capstone requirement. The student and research advisor will agree on the specific topics and deliverables on a per-project basis. The project must include substantial research, analysis and/or design related to robotics engineering and will conclude with a substantial written report and public presentation.

The research advisor of the RBE 598 course must be affiliated with the RBE Department.

Transfer Credit

A student may petition for permission to use graduate courses taken at other accredited, degree-granting institutions to satisfy RBE graduate degree requirements. A maximum of 12 graduate credits, with a grade of B or better, may be satisfied by courses taken elsewhere and not used to satisfy degree requirements at other institutions. Petitions are subject to approval by the RBE Graduate Program Committee, and are then filed with the Registrar. Transfer credit will not be allowed for undergraduate-level courses taken at other institutions. In general, transfer credit will not be allowed for any WPI undergraduate courses used to fulfill undergraduate degree requirements; however, note that there are exceptions in the case of students enrolled in the B.S./M.S. program.

A student with one or more WPI master's degrees who is seeking an RBE master's degree from WPI may petition to apply up to 9 prior credits toward satisfying requirements for the subsequent degree. Petitions are subject to approval by the RBE Graduate Program Committee.

Students who take graduate courses at WPI prior to formal admission to the RBE graduate program may petition to apply up to 9 graduate credits to fulfill the RBE graduate degree requirements. Once again, petitions are subject to approval by the RBE Graduate Program Committee.

For the Ph.D.

The Ph.D. program in Robotics Engineering strives to educate men and women to:

- Have an advanced understanding of Robotics Science, Engineering, and Systems..
- Apply tools and concepts from Management and Systems Engineering to realize robotics systems and exercise professional leadership.
- Make significant research contributions in selected areas of robotics.

Admission Requirements

Students will be eligible for admission to the program if they have earned an undergraduate or graduate degree in Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, Robotics Engineering, or a related field from an accredited university. Applicants must supply a Statement of Purpose, three Letters of Recommendation, and Graduate Record Examination scores. The GRE requirement may be waived for WPI students and alumni, or at the discretion of the Robotics Engineering Graduate Program Committee when supplied with additional supporting materials such as published papers or a record of work experience. Admission decisions will be made by the Robotics Engineering Graduate Program Committee based on all of the information presented in the application.

Degree Requirements

The Ph.D. program in Robotics Engineering requires 60 credit hours of work beyond the M.S. degree or 90 credit hours beyond the B.S degree. Coursework must include 3 credit hours of Management or Systems Engineering courses at the 500 level or above. This requirement may be satisfied as part of the M.S. in Robotics Engineering or other M.S. program. All entering students must submit a plan of study identifying the courses to be taken and a prospective research area before completing more than 9 graduate credits. The plan of study must be approved by the student's academic advisor and submitted to the RBE Graduate Program Committee, and must include the following minimum requirements:

For students entering with an M.S., the 60 credits shall be distributed as follows:

1. Coursework, including Special Topics and Independent Study (12 credits). If not already included in the M.S. degree, the credits must include 3 credit hours of Management courses at the 500 level or above, or 3 credit hours of Systems Engineering courses at the 500 level or above.
2. RBE 699 Dissertation Research (30 credits).
3. Other. Additional coursework, Independent Study, RBE 598 Directed Research or RBE 699 Dissertation Research (18 credits).

For students entering with a B.S., the 90 credits shall be distributed as follows:

1. RBE M.S. Degree Requirements (30 credits).
2. Coursework, including Special Topics and Independent Study (12 credits).
3. RBE 699 Dissertation Research (30 credits).
4. Other. Additional coursework, Independent Study, RBE 598 Directed Research or RBE 699 Dissertation Research (18 credits).

Doctoral Qualifiers

The Doctoral Qualifiers evaluate each student's level of academic preparation. The Doctoral Qualifiers consist of four topic qualifiers: Technical, Writing, Speaking, and Research. The requirements for each qualifier are described in the Graduate Regulations on the RBE website https://www.wpi.edu/academics/departments/robotics-engineering. Doctoral students must successfully complete the Doctoral Qualifiers before 1) completing 30 credits towards the Ph.D. for students entering with M.S., or 60 credits towards the Ph.D. for students entering with B.S., and 2) before completing 18 credits of directed research. Advancement of the student into Ph.D. candidacy is contingent upon successful completion of the Doctoral Qualifiers.

Upon successful completion of the Doctoral Qualifiers, the doctoral student advances to Ph.D. candidacy. Upon failing any topic qualifier, the student may retake the failed topic qualifier one additional time. Failing any topic qualifier twice results in the dismissal from the Robotics Engineering doctoral program. However, students can petition the RBE Graduate Program Committee to review their case. After reviewing the case, the committee can decide to let the student take the qualifier one additional time.

Dissertation

Dissertation Committee

Within one semester after the successful completion of the Doctoral Qualifiers, the student, in consultation with the Research Advisor, assembles a Dissertation Committee. The committee consists of the Research Advisor and three additional members, at least one of whom must be from outside the WPI RBE Program. The Dissertation Committee is responsible for approving the Dissertation Proposal and the Dissertation.

Dissertation Proposal

The Dissertation Proposal describes the student's proposed research. The Dissertation Proposal should be sufficiently detailed to convince the Dissertation Committee of the student's understanding of the problem domain along with the significance of the proposed work.

The Dissertation Proposal must be defended in a public presentation, immediately followed by private questioning from the Dissertation Committee. The Dissertation Committee then determines the outcome of the Proposal Defense. It may accept the proposal, reject the proposal and recommend pursuit of a different topic, or require the student do additional work before reconsidering the proposal. The time frame for the student to do additional work on the Dissertation Proposal is determined by the Dissertation Committee.

Dissertation

All Ph.D. students must complete and orally defend a Dissertation prepared under the supervision of the Research Advisor. The research described in the Dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Dissertation must be defended in a public presentation, immediately followed by private questioning from the Dissertation Committee. The Dissertation Committee then determines the outcome of the Dissertation Defense, certifying the quality and originality of the research, and the satisfactory execution of the Dissertation. It may accept the Dissertation with or without revisions, reject the Dissertation, or require the student do additional work before reconsidering the Dissertation. The time frame for the student to complete additional work is determined by the Dissertation Committee.

B.S./M.S. in Robotics Engineering

WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelors-Masters program. This 12 credit overlap can be achieved through the following mechanisms:

- Up to 12 graduate credits in RBE, CS, ECE, or ME taken by the student may be counted towards meeting the engineering/science/elective requirements of the student's undergraduate major, subject to approval by his/her major department.
- Up to 4 credits (2/3 undergraduate units) of 4000-level undergraduate courses taken by the student in his/her undergraduate major program may be counted towards the requirements of the Masters Degree in Robotics Engineering if they can be placed in one of the requirement categories listed above and are approved by the Robotics Engineering Graduate Program Committee.
- Up to 3 credits (1/2 undergraduate unit) can be earned towards fulfillment of the thesis requirement by double counting a Major Qualifying Project, provided that:
  - the MQP involves substantial use of Robotics Engineering at an advanced level,
  - the thesis research is a continuation or extension of the MQP work,
  - the student satisfies the thesis requirement by completing at least 6 additional credits of RBE 599 Thesis Research, and
  - the thesis advisor and Robotics Engineering Graduate Program Committee approve the double counting.

MQP work may not be double-counted toward the non-thesis option.

Summary of Credit Requirements

		Non-Thesis		Thesis	
		M.S. Only	B.S./M.S.	M.S. Only	B.S./M.S.
Robotics Core	Foundations	9	9	9	9
	Other Core	6	6	6	6
Engineering Context		3	3	3	3
Electives		9	9	3	3
Thesis		—	—	9	MQP+6
Capstone Course/Research/Practicum		3	3	—	—
Double Counted Courses		—	(12)	—	(9)
Total		30	18	30	18

Robotics Engineering Laboratories

Adaptive and Intelligent Robotics (AIR) Lab

Professor Jing Xiao

The AIR Lab is located at 301 (3rd floor) of 85 Prescott Street. Research at the AIR Lab is focused on robotic systems that can best adapt to unknowns, uncertainties, and changes in the working environments, through real-time perception, planning, learning, and execution in seamless synergy. Interested areas include robotic assembly, manipulation, and navigation in human-centered environments, with different kinds of manipulators, from articulated to continuum/soft robots, and in a wide range of applications, including assembly, additive manufacturing, material handling, maintenance and repair, medical and healthcare, manufacturing, and services. Further information is available at https://wp.wpi.edu/airlab/home/

Automation and Interventional Medicine (AIM) Lab

Professor Gregory Fischer

The Automation and Interventional Medicine Laboratory Robotics Research Laboratory (AIM Lab) is located at Gateway Park. The primary focus of projects in the AIM Lab is medical robotics including: robotic surgery, image-guided surgery, MRI-compatible mechatronics, rehabilitation robotics, socially assistive robotics, and biofabrication. The lab contains student workstations, equipment for mechanical and electrical design, construction, configuration, and testing of robots, control systems, and automated test fixtures, including state-of-the-art electronics testing and micro-electronics assembly equipment and supplies. An optical tracker is available for motion capture. The lab houses MRI robot controllers developed in the AIM Lab and custom control electronics for high precision control of piezoelectric motor drive waveforms and corresponding robotic system testbeds. A daVinci Research Kit (dVRK) surgical robot is also available in the lab which includes the Intuitive Surgical robot with custom open control systems. Access to medical imaging in a clinical site is available through collaboration with the nearby UMass Medical School and with the Brigham and Women's Hospital. The research in the AIM Lab is directed by Prof. G. Fischer. Further information can be found at http://aimlab.wpi.edu/.

Cognitive Medical Technology (COMET) and Robotics Laboratory

Professor Loris Fichera

Research in the COMET Laboratory focuses on the development of smart medical devices and robots. Specific focus areas include autonomous and semi-autonomous surgical robotics, continuum (continuously flexible) surgical instruments and image-guided surgery. The lab features state-of-the-art experimental equipment, including two surgical laser systems (10,600 and 532 nm), an NDI Aurora electromagnetic tracker, a FLIR A655sc thermal camera and a Franka Emika 7-DoF Panda manipulator. The lab has research collaborations with clinical partners at Brigham and Women's Hospital (Boston, MA), Vanderbilt University Medical Center (Nashville, TN) and the Children's National Hospital (Washington, D.C.). The lab is located in room 4832 at 50 Prescott St. and is directed by Prof. L. Fichera. Further information is available at https://comet-lab.github.io/

Computational Intelligence and Bionic Robotics (CIBR)

Professor Jie Fu, Professor Zhi Li and Professor Carlo Pinciroli

CIBR lab is a joint lab among ECE faculty Jie Fu, ME faculty Zhi Li and CS faculty Carlo Pinciroli, under the Robotics Engineering Program. Our research focus is to bring a joint force between control theory, machine learning and robotics to achieve two major objectives: First, by leveraging learning-based control design, we aim to develop algorithms to achieve provably safe, adaptive and robust performance in autonomous systems in the presence of uncertain and dynamical environment. Second, we aim to build the algorithmic foundation for bionic robotics that facilitates a seamless collaboration between human and robots, with applications to advanced medical, space and military robotics.

Control and Intelligent Robotics Laboratory (CIRL)

Professor Jie Fu

The Control and Intelligent Robotics Laboratory (CIRL) is located at 85 Prescott Street (Gateway Park). The primary focus is for developing theory and algorithms that support intelligent and (semi-)autonomous systems through the integration of control theory, machine learning, and formal methods. Specifically, we aim to construct trustworthy and adaptive control systems with complex decision-making capabilities in dynamic environments. Research in CIRL lab is directed by Prof. Jie Fu. Further information can be found at http://labs.wpi.edu/cirl/.

Human-inspired Robotics (HIRO) Lab

Professor Zhi Li

The Human-inspired Robotics lab aims to achieve the high-level synergy of human and robotic systems. Specifically, we apply the motion control strategies discovered in human movement science to the design of robot automation. Our research primarily focuses the wearable robots and humanoid robots that augment and collaborate with human workers in healthcare, space, warehouse applications. Our current projects include: perception-action coordination of cyber-human system, computational modeling of physical human-robot interaction, high-level learning and planning of human-robot collaboration. Further information is available at http://labs.wpi.edu/hiro/

Manipulation and Environmental Robotics (MER) Lab

Professor Berk Calli

The Manipulation and Environmental Robotics Lab primarily focuses on enhancing manipulation capabilities of robots. The research integrates visual feedback, advanced control methods, active vision framework, machine learning algorithms and intelligent mechanical design to achieve robust and dexterous robotic systems. Such systems are essential for executing grasping and manipulation tasks in unstructured environments, including homes, offices, modern warehouses, and collaborative manufacturing stations. One of the main themes of the lab is environmental robotics, i.e. utilizing robots to solve environmental problems such as waste management issues and recycling efficiency. The lab is directed by Prof. Berk Calli. Further information is available at https://wp.wpi.edu/merlab/

Medical Frontier Ultrasound Imaging and Robotic Instrumentation (FUSION) Lab

Professor Haichong (Kai) Zhang

Medical FUSION (Frontier Ultrasound Imaging and Robotic Instrumentation) Lab focuses on the interface of medical robotics, sensing, and imaging, and to develop robotic assisted imaging systems as well as image-guided robotic interventional platforms, where ultrasound and photoacoustic (PA) imaging are two key modalities to be investigated and integrated with robotics. The scope of innovation focuses on medical robotics, sensing and imaging for (1) co-robotic imaging, where a robotic component is essential to reduce user-dependency in ultrasound scanning, to build an image with higher resolution and contrast, and to miniaturize and simplify imaging platform and (2) PA-based functional image-guided interventions that give additional information for surgical guidance with high sensitivity and specificity. Further, we will also tackle (3) mathematical and algorithmic challenges behind computer assisted interventions such as hand-eye calibration to support these deployments. The developed systems will synergistically improve both image quality and surgical accuracy and specificity towards diagnostic and interventional applications. https://medicalfusionlab.wordpress.com/

Nemitz Robotics Group

Professor Markus Nemitz

Our group seeks to blur the line between robots and materials by embedding intelligence into elastomeric polymers and textiles. We develop robotic soft materials using fluidics, magnetics, and machine learning. Our multi-disciplinary research aims for developing co-bots, collaborative robots that support, protect, and interact with humans, with specialized applications in healthcare and (under-) water environments. Our group is located in room 308 at 85 Prescott Street. For more information please visit: http://www.nemitzroboticsgroup.com

Novel Engineering of Swarm Technologies (NEST) Lab

Professor Carlo Pinciroli

The Novel Engineering for Swarm Technologies (NEST) Laboratory focuses on the design of algorithms and software tools for swarm robotics and human interaction, with applications to disaster recovery and firefighting. The lab offers a swarm of 10 Khepera IV robots (along with extension modules such as grippers and LIDARs) and 100 Kilobots. In addition, the lab has a dedicated experimentation area equipped with a Vicon motion capture system comprising 10 cameras (2.2 Megapixel resolution at 330 frames per second, with varifocal lenses and an IR strobe), a dedicated 1 Gb network connected to a workstation through Vicon Lock+, and the latest version of Vicon image analysis software (Vicon Nexus Standalone, Vicon BodyBuilder, Tracker 3.0 Standalone). The research is conducted in collaboration with MathWorks (Natick, MA). The lab is located in 85 Prescott Street and is directed by Prof. Carlo Pinciroli. Further information is available at https://www.nestlab.net.

PracticePoint

PracticePoint is a Massachusetts Technology Collaborative (MassTech) supported R&D center that seeks to improve healthcare technologies and develop new medical cyber-physical systems. PracticePoint provides an agile and scalable, collaborative research facility empowering public and private universities, research institutions, industry and innovators to incorporate cyber-physical systems into medical devices and equipment that will improve performance, security, accuracy, timeliness, costs and outcomes in human healthcare. PracticePoint fosters collaborations among its affiliates through state-of-the-art clinical care test beds, secured project pods, collaboration suites and shared tool bays. The point-of-practice environments including: medical imaging coupled with a hybrid operating room suite (including an MRI scanner), a controlled care environment (reconfigurable as ICU, exam room, and recovery room), rehabilitative care suites (including motion capture and rehab equipment), and a residential setting (highly instrumented mock home environment). These point-of-practice care suites are co-located we will have advanced manufacturing (including CNC machining, 3D printing, laser cutting), electronics assembly and test equipment, and build areas. The facility also comprises office spaces for faculty and graduate students, individual research group lab spaces, and reconfigurable "lab pods." Further information can be found at http://practicepoint.org.

Robotics, Mobility, and Cyber-Physical Systems Laboratory

Professor Xiangrui Zeng

Robotics, Mobility, and Cyber-Physical Systems Lab focuses on developing and applying data-enhanced intelligent control algorithms to improve the performance of a variety of cyber-physical systems, especially those involve robotics and mobility. The research combines optimal control and machine learning with applications in robotics, connected and automated vehicles, as well as intelligent transportation systems. The ultimate goal is to design comprehensive tools utilizing all available data to achieve optimal performance for cyber-physical systems.

WPI Humanoid Robotics Laboratory (WHRL)

Professor Michael Gennert

The WPI Humanoid Robotics Laboratory in Washburn 108 conducts research into humanoid locomotion, perception, control, planning, and user interfaces. WHRL features WARNER (WPI's Atlas Robot for Non-conventional Emergency Response) and a custom-designed humanoid platform. We are working on many exciting research projects: 2-handed manipulation, handing objects between Atlas and a human, generic humanoid software that can run on Atlas and Valkyrie, designing a low-cost humanoid, competing in the next phase of the NASA Space Robotics Challenge, and more. Advanced software includes Gazebo simulator, RViz visualization software, MoveIT! trajectory planner, TrajOpt trajectory optimizer, ROS middleware, and the OpenCV and Point Cloud Library packages. Further information is available at http://ecewp.ece.wpi.edu/wordpress/whrl/.

WPI Popovic Labs

Professor Marko Popovic

Researchers study physics, biomechanics and robotics with a goal to answer how living systems function and to synthesize systems that have resembling architecture and functionality and/or may improve life. Numerous biomechatronics projects include advanced prosthetics, braces, exoskeletons, exo-musculatures, exo-suits, physical therapy and assistive devices. Researchers also work on bioinspired robots, physical intelligence, new actuators, transmission mechanisms, valves, intelligent structural elements, and novel propulsion methods. Through close connection with industry partners a lot of research activity is focused on novel industrial robotics. Lab houses various equipment, manufacturing tools as well as one of the most advanced 3D printers on campus. Lab is also home to big dual arm Yaskawa robot. Learn more at http://users.wpi.edu/~mpopovic/

WPI Robot Communications and Navigation Laboratory

Professor William Michalson

The Robot Communications and Navigation Laboratory at 85 Prescott street conducts research into the navigation of and communications with air, land and sea robots in indoor and outdoor locations. The laboratory has platforms for land robots as well as several rotorcraft and sailing platforms and has competed in intelligent ground vehicle and sea vehicle competitions.

WPI Soft Robotics Laboratory

Professor Cagdas Onal

The Soft Robotics Laboratory is located in HL 127, and supports personnel and equipment required for the design, development, and control of next-generation soft, flexible, and semi-rigid robotic systems. Projects in the lab include studying and developing soft robotic snakes, octopus arms, origami-inspired hexapods, tentacles, flying robots, wearable haptic interfaces, human-robot interaction, and multi-robot systems.

Equipment in the Soft Robotics lab includes tools for design, fabrication, experimentation, and analysis, including an Epilog Zing 24 CO2 laser cutter, a dual nozzle 3D printer, a motion capture area, various semi-rigidware packages for mechanical and electronic design, a full custom-made flexible circuit fabrication and assembly equipment suite, a large-workspace optical microscope, an elastomeric fabrication workbench, and various data acquisition and analysis systems. The lab currently supports research activities in elastomeric robotic systems, printed circuit and sensor manufacturing, origami-inspired foldable systems, assistive soft robotic monitoring, bio-inspired stereo vision, and prosthetic robotics. Research in the Soft Robotics Laboratory is directed by Prof. Onal. Further information can be found at http://softrobotics.wpi.edu/.

Course Descriptions

All courses are 3 credits unless otherwise noted.

RBE 500. Foundations of Robotics

Fundamentals of robotics engineering. Topics include forward and inverse kinematics, velocity kinematics, introduction to dynamics and control theory, sensors, actuators, basic probabilistic robotics concepts, fundamentals of computer vision, and robot ethics. In addition, modular robot programming will be covered, and the concepts learned will be applied using realistic simulators. (Prerequisites: Differential Equations (MA 2051 or equivalent), Linear Algebra (MA 2071 or equivalent) and the ability to program in a high-level language.)

RBE/ME 501. Robot Dynamics

Foundations and principles of robotic manipulation. Topics include computational models of objects and motion, the mechanics of robotic manipulators, the structure of manipulator control systems, planning and programming of robot actions. The focus of this class is on the kinematics and programming of robotic mechanisms. Important topics also include the dynamics, control, sensor and effector design, and automatic planning methods for robots. The fundamental techniques apply to arms, mobile robots, active sensor platforms, and all other computer-controlled kinematic linkages. The primary applications include robotic arms and mobile robots and lab projects would involve programming of representative robots. An end of term team project would allow students to program robots to participate in challenges or competitions. (Prerequisite: RBE 500 or equivalent.)

RBE 502. Robot Control

This course demonstrates the synergy between the control theory and robotics through applications and provides an in-depth coverage of control of manipulators and mobile robots. Topics may include kinematic and dynamic models, trajectory and motion planning, feedback control, compliance and force control, impedance control, control of redundant manipulators, control of underactuated robots, adaptive robot control, integrated force and motion control, digital implementation of control laws, model identification and parameter estimation techniques. Course projects will emphasize modeling, simulation and practical implementation of control systems for robotic applications. (Prerequisites: Linear algebra; Differential equations; Linear systems and control theory as in ECE 504 or consent of the instructor.)

RBE 510/ME 5204. Multi-Robot Systems
(2 credits)

This course covers the foundation and principles of multi-robot systems. The course will cover the development of the field and provide an overview on different control architectures (deliberative, reactive, behavior-based and hybrid control), control topologies, and system configurations (cellular automata, modular robotic systems, mobile sensor networks, swarms, heterogeneous systems). Topics may include, but are not limited to, multi-robot control and connectivity, path planning and localization, sensor fusion and robot informatics, task-level control, and robot software system design and implementation. These topics will be pursued through independent reading, class discussion, and a course project. The course will culminate in a group project focusing on a collaborative/cooperative multi-robot system. The project may be completed through simulation or hands-on experience with available robotic platforms. Groups will present their work and complete two professional-quality papers in IEEE format. (Prerequisites: Linear algebra, differential equations, linear systems, controls, and mature programming skills, or consent of the instructor.) Students cannot receive credit for this course if they have taken the Special Topics (ME 593S) version of the same course.

RBE 520. Biomechanics and Robotics

This course introduces Biomechanics and Robotics as a unified subject addressing living and man-made “organisms”. It draws deep connections between the natural and the synthetic, showing how the same principles apply to both, starting from sensing, through control, to actuation. Those principles are illustrated in several domains, including locomotion, prosthetics, and medicine. The following topics are addressed: Biological and Artificial sensors, actuators and control, Orthotics Biomechanics and Robotics, Prosthetic Biomechanics and Robotics: Artificial Organs and Limbs, Rehabilitation Robotics and Biomechanics: Therapy, Assistance and Clinical Evaluation, Human-Robot Interaction and Robot Aided Living for Healthier Tomorrow, Sports, Exercise and Games: Biomechanics and Robotics, Robot-aided Surgery, Biologically Inspired Robotics and Micro- (bio)robotics, New Technologies and Methodologies in Medical Robotics and Biomechanics, Neural Control of Movement and Robotics Applications, Applied Musculoskeletal Models and Human Movement Analysis. This course meshes physics, biology, medicine and engineering and introduce students to subject that holds a promise to be one of the most influential innovative research directions defining the 21st century. (Recommended background: foundation of physics, linear algebra and differential equations; basic programming skills e.g. using MATLAB, undergraduate level biomechanics, robotics)

RBE/ME 521. Legged Robotics

Foundations and principles of parallel manipulators and legged robots. Topics include advanced spatial/3D kinematics and dynamics of parallel manipulators and legged robots including workspace analysis, inverse and forward kinematics and dynamics, motion analysis and control, and gait and stability/balance analysis of legged robots. The course will be useful for solving problems dealing with parallel manipulators as well as multi-legged robots including, but not limited to, quadruped robots, hexapod robots and any other types of multi-legged robots. A final term project allows students to show mastery of the subject by designing, analyzing, and simulating parallel and/or legged robots of their choice.

Recommended Background: RBE 500, RBE 501.

RBE 526/CS 526. Human-Robot Interaction

This course focuses on human-robot interaction and social robot learning, exploring the leading research, design principles and technical challenges we face in developing robots capable of operating in real-world human environments. The course will cover a range of multidisciplinary topics, including physical embodiment, mixed-initiative interaction, multi-modal interfaces, human-robot teamwork, learning algorithms, aspects of social cognition, and long-term interaction. These topics will be pursued through independent reading, class discussion, and a final project. (Prerequisites: Mature programming skills and at least undergraduate level knowledge of Artificial Intelligence, such as CS 4341. No hardware experience is required.) RBE 595 (Synergy of Human & Robot) and the RBE/CS 526 (Human-Robot Interaction) courses are equivalent. A student cannot take and get credit for both courses.

RBE/ME 530. Soft Robotics
(2 credits)

Soft robotics studies “intelligent” machines and devices that incorporate some form of compliance in their mechanics. Elasticity is not a byproduct but an integral part of these systems, responsible for inherent safety, adaptation and part of the computation in this class of robots. This course will cover a number of major topics of soft robotics including but not limited to design and fabrication of soft systems, elastic actuation, embedded intelligence, soft robotic modeling and control, and fluidic power. Students will implement new design and fabrication methodologies of soft robots, read recent literature in the field, and complete a project to supplement the course material. Existing soft robotic platforms will be available for experimental work. Prerequisites: Differential equations, linear algebra, stress analysis, kinematics, embedded programming.

RBE 533. Smart Materials & Actuation

This hands on course covers smart materials and actuation, with an emphasis on electroactive polymer (EAP) based materials and actuators, such as contractile EAPs, dielectric elastomers (DEAs), and ion-polymer metal composites (IPMCs). Piezoelectric materials and shape memory alloys (SMAs) are included in the course, as well as pneumatic actuation. Because smart materials and electroactivity are relatively new fields, the course involves literature reviews. Each team project will involve two different types of smart materials, where at least one smart material is electroactive. For the team projects, the class will be organized into groups, ensuring that each group had a mixture of different disciplines to promote lively discussion. Two papers will be required, one as a literature review and one about aspects of the team project. Much of the theory and applied research is yet to be done with smart materials, so this is a very creative course that implements design into the projects, which can include biomimicry.

RBE/CS 549. Computer Vision

This course examines current issues in the computer implementation of visual perception. Topics include image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification and object recognition. We will discuss various representations for visual information, including sketches and intrinsic images. (Prerequisites: CS 534, CS 543, CS 545, or the equivalent of one of these courses.)

RBE 550. Motion Planning

Motion planning is the study of algorithms that reason about the movement of physical or virtual entities. These algorithms can be used to generate sequences of motions for many kinds of robots, robot teams, animated characters, and even molecules. This course will cover the major topics of motion planning including (but not limited to) planning for manipulation with robot arms and hands, mobile robot path planning with non-holonomic constraints, multi-robot path planning, high-dimensional sampling-based planning, and planning on constraint manifolds. Students will implement motion planning algorithms in open-source frameworks, read recent literature in the field, and complete a project that draws on the course material. The PR2 robot will be available as a platform for class projects. Physical robot platforms will be available for class projects. Prerequisites: Undergraduate Linear Algebra, experience with 3D geometry, and significant programming experience.

Return to Table of Contents

RBE 580/ME 5205. Biomedical Robotics
(2 credits)
This course will provide an overview of a multitude of biomedical applications of robotics. Applications covered include: image-guided surgery, percutaneous therapy, localization, robot-assisted surgery, simulation and augmented reality, laboratory and operating room automation, robotic rehabilitation, and socially assistive robots. Specific subject matter includes: medical imaging, coordinate systems and representations in 3D space, robot kinematics and control, validation, haptics, teleoperation, registration, calibration, image processing, tracking, and human-robot interaction.Topics will be discussed in lecture format followed by interactive discussion of related literature. The course will culminate in a team project covering one or more of the primary course focus areas. (Prerequisites: Linear algebra, ME/RBE 501 or equivalent.) Students cannot receive credit for this course if they have taken the Special Topics (ME 593U) version of the same course.

RBE 594. Capstone Project Experience in Robotics Engineering
This project-based course integrates robotics engineering theory and practice, and provides the opportunity to apply the skills and knowledge acquired in the Robotics Engineering curriculum. The project is normally conducted in teams of two to four students. Students are encouraged to select projects with practical significance to their current and future professional responsibilities. The projects are administered, advised, and evaluated by WPI faculty as part of the learning experience, but students are also encouraged to seek mentorship from experienced colleagues in the Robotics Engineering profession. The project will include substantial analysis and/or design and conclude with a written report and a public presentation. (Prerequisites: Since the Capstone Project will draw on knowledge obtained throughout the degree program, it is expected that students will have completed most or all of the coursework within their plan of study before undertaking the capstone project.)

RBE 595. Special Topics
Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular Robotics Engineering course offerings. Exact course descriptions are disseminated by the Robotics Engineering Program well in advance of the offering. (Prerequisite: Consent of instructor.)

RBE 596. Robotics Engineering Practicum
This practicum provides an opportunity to put into practice the principles studied in previous courses. It will generally be conducted off campus and will involve real-world robotics engineering. Overall conduct of the practicum will be supervised by a WPI RBE faculty member; an on-site liaison will direct day-to-day activity. For a student from industry, an internship may be sponsored by his or her employer. The project must include substantial analysis and/or design related to Robotics Engineering and will conclude with a substantial written report. A public oral presentation must also be made, to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison and one additional WPI faculty member. This committee will verify successful completion of the internship. (Prerequisite: Consent of practicum faculty advisor.)

RBE 597. Independent Study
Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. (Prerequisite: B.S. in CS, ECE, ME, RBE or equivalent and consent of advisor.)

RBE 598. Directed Research
For M.S. or Ph.D. students wishing to gain research experience peripheral to their thesis topic, M.S. students undertaking a capstone design project, or doctoral students wishing to obtain research credit prior to admission to candidacy. The project will include substantial analysis and/or design and conclude with a written report and a public presentation. (Prerequisite: Consent of an RBE affiliated research advisor.)

RBE 599. Thesis Research
For master's students wishing to obtain research credit toward the thesis. (Prerequisite: Consent of thesis advisor.)

RBE 699. Dissertation Research
For Ph.D. students wishing to obtain a research credit towards the dissertation. Prerequisite: Consent of research advisor.

Return to Table of Contents

Science and Technology for Innovation in Global Development

Faculty

WPI

Emmanuel Agu, Computer Science

Laureen Elgert, International Development, Environment and Sustainability*

Glenn Gaudette, Biomedical Engineering*

Robert Krueger, Social Sciences and Policy Studies, and Program Director

Geoff Pfeifer, Department of Global Studies

Anita Mattson, Chemistry and Biochemistry*

Pratap Rao, Mechanical Engineering*

Jennifer Rudolph, Humanities and Arts

Elke Rundensteiner, Data Science*

Aaron Sakulich, Civil and Environmental Engineering*

Alex Smith, Economic Sciences*

Steve Taylor, Foisie School of Business*

Yunus Telliel, Humanities and Arts

Pam Weathers, Biology and Biotechnology*

Craig Wills, Computer Science*

*Denotes faculty school/department/program liaison

Clark University

Edward Carr, International Development, Community, and Environment (IDCE)

Timothy Downs, Environmental Science, IDCE

Yelena Himmelberger, GIS and Remote Sensing, IDCE

Anthony Bebbington, Graduate School of Geography

Denise Humphreys Bebbington, International Development, IDCE

James Murphy, Graduate School of **Geography**

Morgan Ruelle, IDCE

Lis Gilmore, IDCE

Shadrock Roberts, IDCE

Affiliated Departments and Programs at WPI

Biomedical Engineering

Biology and Biotechnology

Chemistry and Biochemistry

Data Science Program

Economics Science Program

Foisie School of Business

Global Studies

Interactive Media and Game Development

Humanities and Arts

International Development, Environment and Sustainability Program

Social Sciences and Policy Studies

Program of Study

Master of Science in Science and Technology for Global Development

Admissions Requirements

Students applying to the Science and Technology for Innovation in Global Development program are expected to have an undergraduate degree.

Degree Requirements

Students pursuing the MS degree in Science and Technology for Innovation in Global Development must complete a minimum of 30 credits of relevant work at the graduate level. In some cases, students may enter the program if they have a related graduate certificate. Students may not retake courses they have already taken at WPI or elsewhere.

There are two project options satisfaction of the degree requirements. Students may take a three-credit Graduate Qualifying Project (GQP) or a six-credit MS thesis. Students will typically have a field experience no matter which track they choose. The MS degree with a GQP concentration can be completed in twelve months. The MS degree with the Thesis option will typically take one-and-a-half to two academic years. If a student seeks to add a language to their study, the program will take two years.

GQP Track

Graduate Qualifying Field Project (3 Credits)

Concentration and Electives (12 Credits)

Design for Social Change (3 Credits)	Design Studio 1 (1 Credit)	Design Studio 2 (2 Credits)	Ethics in Design (3 Credits)	Research Methods (3 Credits)

Social Innovation and Global Development (3 Credits)

Thesis Track

MS Field-Based Thesis (6 Credits)

Concentration and Electives (9 Credits)

Design for Social Change (3 Credits)	Design Studio 1 (1 Credit)	Design Studio 2 (2 Credits)	Ethics in Design (3 Credits)	Research Methods (3 Credits)

Social Innovation and Global Development (3 Credits)

Return to Table of Contents

Upon acceptance to the MS Program, a student will be assigned to a team of academic advisors from different disciplines. In consultation with that committee the student must prepare a Plan of Study that outlines the pathway the student will take to meet the MS degree requirements.

Core Coursework Requirement (15 Credits)

A student in the Science, Technology, and Innovation for Global Development program must take the Design Boot Camp, which begins in mid-August each year.

Design Thinking for Social Innovation in Global Development Sequence

DEV 501 Social Innovation and Global Development

DEV 4400/Dev 502 Design for Social Change

DEV 510 Design Studio 1 (1 unit)

DEV 520 Design Studio 2 (2 units)

DEV 530 Ethics and Social Justice in Science, Engineering, and Development

DEV 540 Research Methods

Graduate Qualifying Project / MS Thesis (3 – 6 Credits)

DEV 598 Graduate Qualifying Project (3 credits) / DEV 599 Master's Thesis (6 Credits)

Areas of Concentration (9-12 Credits)

A student in the Science and Technology for Innovation in Global Development program must take course work from the program electives below to satisfy the 30 required units for graduation. An elective may be any of these graduate-level courses and undergraduate courses as approved by the advisory committee and a department liaison. Students must have the prerequisite knowledge, if required, to take courses outside the program.

While design thinking for science and technology for innovation in global development is at the core of this degree requirement students may tailor their program to suit their professional needs.

Course selection should provide a logical program of study. We expect that the elective courses will add depth in at least one concentration. The list of pre-approved courses follows. Other courses may be acceptable but will require approval from the advisory committee and the department liaison (when necessary).

List of Program Concentration and Elective Courses

Concentrations

Biology*

BB 515. Environmental Change: Problems and Approaches

BB 551. Research Integrity in the Sciences

BB 553. Experimental Design and Statistics

BB 554. Journal Club

BB 561. Model Systems: Experimental Approaches and Applications

*Other courses, graduate or undergraduate, may be approved after consultation with the department liaison and the instructor's permission. Students may satisfy requirements through the certificate program in Life Science Management.

Biomedical Engineering*

BME 531. Biomaterials in the Design of Medical Devices

BME 535. Medical Device Design Controls

BME 592. Healthcare Systems and Clinical Practice

BME 593. Scientific Communication

BME 594. Biomedical Engineering Journal Club

BME 595. Special Topics in Biomedical Engineering

BME 698. Laboratory Rotation in Biomedical Engineering

*These and other courses in BME could be taken after consultation with the department liaison and the instructor's permission.

Chemistry and Biochemistry*

TBD

*Courses may be taken after consultation with the department liaison and the instructor's permission. Courses under 4000-level will require extra work and will be negotiated by the department liaison and the course instructor. Courses cannot duplicate a course the student has taken as an undergraduate.

Economics*

ECON 2125. Development Economics

ECON 2126. Public Economics

ECON 2130. Econometric Modeling

ECON 2145. Behavioral Economics

ECON 2155. Experimental Economics

*These courses may be taken after consultation with the program liaison and the instructor's permission. Courses under 4000-level will require extra work and will be negotiated by the program liaison and the course instructor. Courses cannot duplicate a course the student has taken as an undergraduate.

Foisie School of Business*

BUS 2080. Data Analysis for Decision Making

BUS 3010. Creating Value through Innovation

ETR 2900. Social Entrepreneurship

ETR 500. Entrepreneurship and Innovation

ETR 593. Technology Commercialization: Theory, Strategy, and Practice

ETR 596. Selling and Sales

OBC 505. Teaming and Organizing for Innovation

OBC 506. The Heart of Leadership: Power, Reflection, and Interpersonal Skills

OBC 533. Negotiations

OBC 537. Leading Change

OBC 538. Developing Managerial Talent

*These and other courses in the FSB could be taken after consultation with the school liaison and the instructor's permission. Courses under 4000-level will require extra work and will be negotiated by the school liaison and the course instructor. Courses cannot duplicate a course the student has taken as an undergraduate.

Civil and Environmental Engineering*

CE 542. Geohydrology

CE 560. Advanced Principles of Water Treatment

CE 561. Advanced Principles of Wastewater Treatment

CE 562. Biosystems in Environmental Engineering

CE 563. Industrial Waste Treatment

CE 565. Surface Water Quality Monitoring

CE 566. Groundwater Flow and Pollution

CE 572. Physical and Chemical Treatment Processes

CE 574. Water Resource Management

CE 567. Hazardous Waste Management

CE 570. Contaminate Fate and Transport

*These and other courses in CEE could be taken after consultation with the department liaison and the instructor's permission. Courses cannot duplicate a course the student has taken as an undergraduate.

Data Sciences* +*

CS5007. Introduction to Applications of Computer Science with Data Structures and Algorithms

DS 517. Mathematical Foundations for Data Science

DS 501. Introduction to Data Sciences+

DS 502. Statistical Methods for Data Science

CS 542. Database Management Systems –or—MIS571. Database Applications Development CS 548. Knowledge Discovery and Data Mining CS 539. Machine Learning

DS 503. Big Data Management

DS 504. Big Data Analytics (on-line)

*These and other courses in DS could be taken after consultation with the program liaison. +This course is required for everyone who seeks this concentration.

+*This concentration can be satisfied if students take the Data Science Certificate program

Interactive Media and Gaming*

IMGD 5100. Immersive Human-Computer Interaction

IMGD 5200. History and Future of Immersive Interactive Media and Gaming

IMGD 5300. Design of Interactive Experiences

IMGD 5400. Production Management for Interactive Media

*These and other courses in IMGD could be taken after consultation with the department liaison and the instructor's permission.

Clark IDCE Courses

IDCE 360: Development Theory

IDCE 361: Development Program and Project Management

IDCE 30102: Case Studies in Environmental Issues and Policy Analysis

IDCE 30118: Science Meets Policy in the Real World

IDCE 30110: Social Policy: Qualitative Methods for Design and Analytics

IDCE 30229: Program Monitoring and Evaluation

IDCE 332: Sustainable Development Assessment and Planning

IDCE 395: Culture, Environment, and Development

IDCE 30245: Natural Resource Management

IDCE 312: Famine and Food Security

IDCE 30248: Theorizing Women, Gender, and Development

IDCE 30254: Gender, Power, and Social Change

IDCE 30275: Gender and Development Planning

IDCE 30306: GIS for International Development in Practice

IDCE 329: Property and Community

IDCE 30701: Beyond the Population Bomb

Course Descriptions

All courses are 3 credits unless otherwise noted.

DEV 501. Social Innovation and Global Development.
Social Innovation and Global Development provides a broad overview of the program. We will touch on many of the themes that will be explored in depth in the core courses. These themes include but are not limited to: design thinking, cross-cultural design, ethics in design, and visual expression. We will also employ team building exercises bring the cohort together as a cohesive group. The mornings will be spent in interactive classroom experiences where students will engage in seminar discussions, small group activities, and feedback sessions. This course will take place in the two weeks leading up to the students first semester in the program. The course will run two weeks, for approximately six hours per day, Monday through Friday.

DEV 502. Design for Social Change.
Everyone is entitled to good design, without distinction of any kind. Race, color, sex, language, religion, political or other opinions, national or social origins, property, birth or other status should have effective visual communication. Social Impact Design Course is a place where student designers learn to create "good design" for the "good of others." Community engagement through community-based design projects is just one aspect of the course. Students will learn additional practice skills in design thinking and cause branding. This course explores various community and professional practices when designing for social change. Through community-based projects with non-profit organizations, students explore the many roles creative professionals can play when executing socially-minded work. Students will be challenged to expand their comprehension of design problem solving for new audiences. Design teams will develop skills in design methodology for visual communication: identifying problems, design research, ideation, and implementation.

DEV 510. Design Studio 1.
This studio course introduces students to a variety of design case studies from developing world infrastructure projects, to human computer interaction, autonomous vehicles, and others to give students an opportunity to explore and critique design processes and to develop a sense of their own approach with some depth.

Return to Table of Contents

DEV 520. Design Studio 2.
This studio course is taken in E(1) term. Here students will begin to develop their own GQP or thesis projects. They will share their work with their peers in weekly feedback sessions. Faculty will act as mentors who push the students toward project and process clarity. For students traveling abroad the studio will provide an opportunity to raise and explore important cultural considerations.

DEV 595. Special Topics in Design for Science, Technology and Innovation.
This course will allow flexibility for faculty to offer courses on topics of current interest. (Prerequisites: will vary on course content)

DEV 596. Independent Study.
This course will allow a student(s) to study a certain topic under the guidance of an affiliated faculty member. The student must produce an appropriate paper (e.g., conceptual or empirical) from this experience.

DEV 597. Directed Research.
Directed research allows students the opportunity to engage in a research project that is related to a member of faculty's portfolio. The student must produce an appropriate paper (e.g., conceptual or empirical) from this experience.

DEV 598. Graduate Qualifying Project.
This three-credit graduate qualifying project, typically done in teams, is to be carried out in cooperation with a sponsor or external partner. It must be overseen by a faculty member affiliated with the Science, Technology, Innovation, and Global Development. This offering integrates theory and practice of design for science, engineering, and innovation, and should include the utilization of tools and techniques acquired in the program. In addition to a written report, this project must be presented in a formal presentation to the WPI community. Professional development skills, such as communication, teamwork, leadership, and collaboration, along with storytelling, will be practiced. (Prerequisite: DEV 501, completion of at least 24 credits of the degree, or consent of the instructor.)

DEV 599. Masters Thesis.
A thesis consists of a research and development project worth (a minimum of) nine graduate credit hours advised by a faculty member affiliated with the Program. A thesis proposal must be approved by the Science, Technology, Innovation, and Global Development Review Board and the student's advisors, before the student can register for more than three thesis credits. The student must satisfactorily complete a written thesis document, and present the results to the WPI community.

Return to Table of Contents

Faculty

STEM Education Center

K.C. Chen, Executive Director; Ph.D., Massachusetts Institute of Technology. Engineering education; PreK-12 STEM education; Materials Science; Community-Based Learning; Diversity, Equity and Inclusion.

M. Cyr, Director of Strategic Growth; Ph.D., Worcester Polytechnic Institute. PreK-12 STEM Education; Engineering Education; Thermofluids.

M. Dubosarsky, Director of Professional Development; Ph.D., University of Minnesota. Science & STEM Education, Curriculum and Instruction, Assessment in Science Education, Education Research, Cooperative Learning Pedagogy, Problem-based Learning.

Learning Sciences and Technologies

N. T. Heffernan, Professor and Director, Learning Sciences and Technologies; Ph.D., Carnegie Mellon University. Intelligent tutoring agents, artificial intelligence, cognitive modeling, machine learning.

I. Arroyo, Associate Professor; Ed.D., M.S., University of Massachusetts, Amherst. Learning with novel technologies; multimedia learning; intelligent tutoring systems; wearable learning and e-Textiles; learner characteristics and their relationship to learning; connection between affect and learning; educational data mining and student modeling.

J. E. Beck, Associate Professor; Ph.D., University of Massachusetts, Amherst. Machine learning, educational data mining, intelligent tutoring systems, human learning and problem solving.

E. Ottmar, Assistant Professor; Ph.D., University of Virginia. Mathematics teaching and learning; mathematics development and cognition; interventions in schools; instructional quality; social and emotional learning; motivation and engagement; perceptual learning; teacher/child interactions; observational measurement development.

Mathematics

J. Goulet, Teaching Professor and Coordinator, Master of Mathematics for Educators Program; Ph.D., Rensselaer Polytechnic Institute, 1976. Applications of linear algebra, cross departmental course development, project development, K-12 relations with colleges, mathematics of digital and analog sound and music.

M. Johnson, Teaching Associate Professor; Ph.D., Clark University 2012. Industrial organization, game theory, graph theory and probability.

B. Servatius, Professor; Ph.D., Syracuse University, 1987. Combinatorics, matroid and graph theory, structural topology, geometry, history and philosophy of mathematics.

Physics

I. Stroe, Associate Teaching Professor and Director of Master of Science in Physics for Educators; Ph.D., Clark University. Experimental biophysics, protein structure, dynamics and functionality.

G. S. Iannacchione, Professor; Ph.D., Kent State University. Soft condensed matter physics/complex fluids, liquid-crystals, calorimetry, and order-disorder phenomena.

F. Dick, Associate Teaching Professor; Ph.D., Worcester Polytechnic Institute. Nuclear and particle physics, astrophysics and planetary.

D. T. Petkie, Department Head and Professor; Ph.D., Ohio State University. Millimeter-wave and Terahertz sensing, spectroscopy, electromagnetic scattering and propagation, photonics, optics and imaging.

R. P. Kafle, Assistant Teaching Professor, Ph.D., Worcester Polytechnic Institute. Experimental biophysics, fluorescence correlation spectroscopy, atom interferometers.

Questions

Contact Kathy Chen, STEM Education Center, kcchen@wpi.edu, 508-831-6221.

Program of Study

Majors in the STEM for Educators program are designed specifically for middle school, high school and community college in-service educators. The majors emphasize coursework in the content area (math or physics) along with classes in core assessment and evaluation theory, and a participant-designed project. Educators will find that this combination of coursework held during afternoon and evening times will both fit their needs as busy professionals and broaden knowledge and skills that will support what they do in their classrooms. The program may satisfy Massachusetts Professional Licensure requirements for middle and high school educators.

Master of Science in Mathematics for Educators (MMED)

This degree blends together an emphasis on courses in mathematics content with core assessment and evaluation theory courses and a participant-designed project. The math content courses, designed for educators, offer a solid foundation in areas such as geometry, algebra, modeling, discrete math and statistics. They additionally include the study of modern applications. Participants have the opportunity to develop materials, based on coursework, which may be used in their own classrooms. Technology is introduced whenever possible to help educators become familiar with the options available for use in classrooms. Examples of this include Geometer's Sketchpad and the TI CBL for motion and heat.

*For information about the Master of Mathematics for Educators program, please look under the Mathematical Sciences page.

Master of Science in Physics for Educators (MPED)

This degree blends together an emphasis on courses in physics content with core assessment and evaluation theory courses and a participant-designed project. The physics content courses are designed to give educators a deep but applicable understanding of physics that both make advanced physics topics easily accessible to educators and appropriate to their roles of guiding their students. The physics content is organized into three parts: Depth (e.g. Mechanics and Topics in Modern Physics), Methods (e.g. Computational and Experimental Physics Methods), and Breadth (e.g. Research Experience for Educators and Physics in Popular Culture). Support for degree candidates extends beyond the specific coursework and projects as participants will become part of a network of physicists which ranges from local individuals to a much broader community.

Admission Requirements

Candidates for any major in the STEM for Educators programs must have a Bachelor's degree, a background equivalent to at least a minor in one of the STEM areas of interest and either a teacher certification in a STEM field or a full-time teaching position in one of these disciplines. Applicants can be teaching at any grade level.

Degree Requirements

Each of the programs within STEM for Educators requires 30 credit hours of work. As part of this, participants must take 9 credits in core assessment and evaluation theory, 15 credits in the content area specific to the major, and 6 credits for the participant-designed project. All courses in these programs are based on a three-semester year where most participants take one to two classes per semester.

Course Requirements

Core Assessment and Evaluation Theory Courses

To fulfill the 9 credits in core assessment and evaluation theory, participants must take a minimum of one course from each of the three sections below. Full course descriptions are listed under the appropriate department.

(a) Learning Theory, Environments, and Cognition:
1) SEME/PSY 501 – Foundations of the Learning Sciences (3 cr)
2) SEME/PSY 502 – Educational Learning Environments (3 cr)
3) SEME/PSY 504 – Meta-cognition, Motivation, and Affect (3 cr)

(b) Qualitative and Quantitative Analysis and Assessment:
4) SEME/MME 524 – Probability, Statistics and Data Analysis I (2 cr)
5) SEME/MME 525 – Probability, Statistics and Data Analysis II (2 cr)
6) SEME/CS 565 – User Modeling (3 cr)
7) SEME/CS 566 – Graphical Models for Reasoning Under Uncertainty (3 cr)
8) SEME/CS 567 – Empirical Methods for Human-Centered Computing (3 cr)

(c) Current Education and Education Research Issues:
9) SEME 562 – Issues in Education (3 cr)
10) SEME/PSY 503 – Research Methods for the Learning Sciences (3 cr)
11) SEME/CS 568 – Artificial Intelligence for Adaptive Educational Tech. (3 cr)

Math Content Courses

15 credit hours of content area courses are required. Full course descriptions are listed under mathematics.

MME 518 – Geometrical Concepts (3 cr)

MME 522 – Applications of Calculus (2 cr)

MME 523 – Analysis with Applications (2 cr)

MME/SEME 524 – Probability, Statistics and Data Analysis I (2 cr)

MME/SEME 525 – Probability, Statistics and Data Analysis II (2 cr)

MME 526 – Linear Models I (2 cr)

MME 527 – Linear Models II (2 cr)

MME 528 – Mathematical Modeling and Problem Solving (2 cr)

MME 529 – Numbers, Polynomials and Algebraic Structures (2 cr)

MME 531 – Discrete Mathematics (3 cr)

(Note that MME/SEME-524/525 are also listed under Core Assessment and Evaluation Theory. Only one of these two courses can be double counted towards the content area.)

Physics Content Courses

The physics content, a total of 15 credit hours, is satisfied with 8 credits in physics depth, 4 credits in physics methods, and 3 credits in physics breadth. Full course descriptions are listed under physics.

Depth Courses

MPE 510 – Classical Mechanics (2 cr)

MPE 520 – Electrodynamics (2 cr)

MPE 530 – Modern Physics (2 cr)

MPE 540 – Differential Equations in Nature (2 cr)

Methods Courses

MPE 550 – Computational Methods in Physics (2 cr)

MPE 560 – Experimental Methods in Physics (2 cr)

Breadth Courses

MPE 572 – Physics Research Experience for Teachers (3 cr)

MPE 574 – Physics for Citizens and Leaders (3 cr)

MPE 576 – Physics in Popular Culture (3 cr)

Culminating Project Courses

Six (6) credit hours are required. Full course descriptions are listed under mathematics.

SEME 602/MME 592 – Project Preparation/Design (2 cr)

SEME 604/MME 594 – Project Implementation (2 cr)

SEME 606/MME 596 – Project Analysis and Report (2 cr)

Course Descriptions

All courses are 3 credits unless otherwise noted.

SEME/PSY 501. Foundations of the Learning Sciences

This course covers readings that represent the foundation of the learning sciences, including: Foundations (Constructivism, Cognitive Apprenticeship, & Situated Learning); Approaches (Project-based Learning, Model-based reasoning, Cognitive Tutors); and Scaling up educational interventions. The goal of this course is for students to develop an understanding of the foundations and approaches to the Learning Sciences so that they can both critically read current literature, as well as build on it in their own research. (Prerequisites: None)

Return to Table of Contents

SEME/PSY 502. Educational Learning Environments
In this class, students will read and review both classic and critical current journal articles about learning technologies developed in the Learning Sciences. This course is designed to educate students on current technological approaches to curricular design, implementation, and research in the Learning Sciences. (Prerequisites: None)

SEME/PSY 503. Research Methods for the Learning Sciences
This course covers research methods used in the Learning Sciences. Students will gain expertise and understanding of think-aloud studies, cognitive task analysis, quantitative and qualitative field observations, log file analysis, psychometric, cognitive, and machine-learning based modeling, the automated administration of measures by computer, and issues of validity, reliability, and statistical inference specific to these methods. Students will learn how and when to apply a variety of methods relevant to formative, performance, and summative assessment in both laboratory and field settings. Readings will be drawn primarily from original source materials (e.g. journal articles and academic book chapters), in combination with relevant textbook chapters. (Prerequisites: SS 2400, Methods, Modeling, and Analysis in Social Science, comparable course, or instructor discretion.)

SEME/PSY 504. Meta-cognition, Motivation, and Affect
This course covers three key types of constructs that significantly impact learning and performance in real-world settings, including but not limited to educational settings. Students will gain understanding of the main theoretical frameworks, and major empirical results, that relate individuals' meta-cognition, motivation, and affect to real-world outcomes, both in educational settings and other areas of life. Students will learn how theories and findings in these domains can be concretely used to improve instruction and performance, and complete final projects that require applying research in these areas to real-world problems. Students will do critical readings on research on this topic. (Prerequisites: None)

SEME/MME 524-25. Probability, Statistics and Data Analysis I, II
(2 credits each)

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills:

- Probability models-mathematical models used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena.
- Data analysis-the art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized.
- Statistical inference and modeling-the use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models, and in drawing inference from data.
- Design of experiments and sampling studies – the proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection, and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package such as MINITAB.

SEME 562. Issues in Education
This course is about the theory and the practice of formative assessment. The practice will involve bringing those theories to life in the classroom. Participants will be required to actively implement the formative assessment cycle in their own teaching. Online tools that facilitate the formative assessment process will be used by the teachers. One such tool that will be required is ASSISTments. Participants will decide what data to collect evaluate and analyze. They will analyze the data in this class and with their students. They will examine their own instruction by videotaping themselves and sharing their experiences with the group. Participants will go through these steps repeatedly during the course. Participants will be required to synthesize and critique course materials through written documents and formal and informal presentations.

SEME/CS 565. User Modeling
User modeling is a cross-disciplinary research field that attempts to construct models of human behavior within a specific computer environment. Contrary to traditional artificial intelligence research, the goal is not to imitate human behavior as such, but to make the machine able to understand the expectations, goals, knowledge, information needs, and desires of a user in terms of a specific computing environment. The computer representation of this information about a user is called a user model, and systems that construct and utilize such models are called user modeling systems. A simple example of a user model would be an e-commerce site which makes use of the user's and similar users' purchasing and browsing behavior in order to better understand the user's preferences. In this class, the focus is on obtaining a general understanding of user modeling, and an understanding of how to apply user modeling techniques. Students will read seminal papers in the user modeling literature, as well as complete a course project where students build a system that explicitly models the user. (Prerequisites: Knowledge of probability.)

SEME/CS 566. Graphical Models for Reasoning Under Uncertainty
This course will introduce students to graphical models, such as Bayesian networks, Hidden Markov Models, Kalman filters, particle filters, and structural equation models. Graphical models are applicable in a wide variety of work in computer science for reasoning under uncertainty such as user modeling, speech recognition, computer vision, object tracking, and determining a robot's location. This course will cover 1) using data to estimate the parameters and structure of a model using techniques such as expectation maximization, 2) understanding techniques for performing efficient inference on new observations such as junction trees and sampling, and 3) learning about evaluation techniques to determine whether a particular model is a good one. (Prerequisites: CS 534 Artificial Intelligence or permission of the instructor.)

SEME/CS 567. Empirical Methods for Human-Centered Computing
This course introduces students to techniques for performing rigorous empirical research in computer science. Since good empirical work depends on asking good research questions, this course will emphasize creating conceptual frameworks and using them to drive research. In addition to helping students understand what makes a good research question and why, some elementary statistics will be covered. Furthermore, students will use and implement computationally intensive techniques such as randomization, bootstrapping, and permutation tests. The course also covers experiments involving human subjects, and some of the statistical and non-statistical difficulties researchers often encounter while performing such work (e.g., IRB (Institutional Review Board), correlated trials, and small sample sizes). While this course is designed for students in Human Computer Interaction, Interactive Media & Game Development, and Learning Sciences and Technologies, it is appropriate for any student with programming experience who is doing empirical research. (Prerequisites: MA 511 Applied Statistics for Engineers and Scientists or permission of instructor.)

SEME/CS 568. Artificial Intelligence for Adaptive Educational Technology
Students will learn how to enable educational technology to adapt to the user and about typical architectures used by existing intelligent tutoring systems for adapting to users. Students will see applications of decision theoretic systems, reinforcement learning, Markov models for action selection, and Artificial Intelligence (AI) planning. Students will read papers that apply AI techniques for the purpose of adapting to users. Students will complete a project that applies these techniques to build an adaptive educational system. (Prerequisites: CS 534 Artificial Intelligence or permission of the instructor.)

System Dynamics

Faculty

O. V. Pavlov, Associate Professor; Ph.D., University of Southern California, 2000. Economics of information systems, political economy, system dynamics, computational economics, complex economic dynamics; opavlov@wpi.edu

M. J. Radzicki, Associate Professor; Ph.D., University of Notre Dame, 1985. Macroeconomics, monetary theory, system dynamics, predictive analytics, automated trading systems; mjradz@wpi.edu

K. Saeed, Professor; Ph.D., Massachusetts Institute of Technology, 1981. Sustainable economic development, system dynamics, organizational development, political economy, health care delivery; saeed@wpi.edu

Adjunct Faculty

K. Chichakly, Ph.D., University of Vermont, 2013. Co-President, ISEE Systems

R. Eberlein, Ph.D., Massachusetts Institute of Technology, 1984. Co-President, ISEE Systems

J. Morecroft, Ph.D., Massachusetts Institute of Technology, 1979. Senior Fellow, Management Science and Operations, London Business School

K. Warren, Ph.D. London Business School, 1995. Chairman, Global Strategy Dynamics

Program of Study

System dynamics is a dynamic computer modeling technique that is primarily used for three interrelated purposes. First, to examine the implications (costs, benefits, trade-offs, etc.) over time of competing system *designs* that alter the structures of complex social, physical, and/or biological systems. Second, to promote *strategic thinking* among model users by facilitating "single and multi-player/competitor" scenarios and "what-if" analyses. And third, to help model users reach an *informed consensus* on proposed changes to the structures of complex social, physical, and/or biological systems.

Although computer simulation modeling used to be an extremely technical area that was limited to specialists, modern software and hardware solutions have made it much more accessible and practical for assisting decision making at any level in or between organizations. As such, there is a strong and growing demand for graduate-level training in complex systems modeling and "systems thinking" in both the public and private sectors. To meet this demand, WPI offers a variety of graduate courses in systems modeling both online and on campus.

WPI's system dynamics program consists of a Graduate Certificate in System Dynamics, a Master of Science in System Dynamics, and an interdisciplinary Master of Science in Systems Modeling. Students may also utilize WPI's interdisciplinary Ph.D. framework to create a unique doctoral program that blends system dynamics modeling with another academic discipline.

Graduate Certificate Program in System Dynamics

Certificate Requirements

WPI's Graduate Certificate in System Dynamics requires fifteen credit hours of graduate study (i.e., five courses). Students must work with a faculty advisor to create a Plan of Study that consists of two foundational modeling courses and three elective courses covering methodological or application topics. A student's Plan of Study must be specified no later than the time of the completion of his or her second graduate system dynamics course.

Admission

A student will be eligible to apply for admission into WPI's Graduate Certificate in System Dynamics program if they have earned an undergraduate degree from an accredited college or university. All admission decisions will be made by the Director of WPI's Graduate Program in System Dynamics. He or she will consider all information contained in a student's application including his/her prior academic performance, professional experience, letters of recommendation, etc.

Master of Science in System Dynamics

The Master of Science in System Dynamics program is designed to prepare students for the professional practice of system dynamics computer simulation modeling. The curriculum is designed to provide students with an understanding of the stock-flow-feedback loop structures that cause observed patterns of behavior in complex social, physical, and/or biological systems, as well as knowledge of the use of dynamic simulation modeling for experimental analysis aimed at solving a variety of problems in the public and private sectors. This training enables students to look across disciplinary boundaries to holistically determine the desired and unintentional impacts of well-intentioned policies and technological solutions, and gives them insights into the policy implementation process in a variety of organizational settings.

Many organizations are currently supporting the training of their managers in systems thinking and system dynamics as they regard these perspectives essential for successfully navigating the modern world. Combined with an undergraduate degree in engineering, the life sciences, business, the humanities, or the social sciences, a Master Degree in System Dynamics enables a decision maker to more fully understand cross-disciplinary issues and thus contribute in innovative ways to their organization's success. WPI's Master of Science in System Dynamics may be pursued online or on campus.

Degree Requirements

WPI's Master of Science in System Dynamics requires thirty credit hours of graduate study (i.e., ten courses). At least twenty-one of these credits must be earned by taking courses in system dynamics. Students may select courses from three categories: (1) Foundational Courses (six credits), (2) Methodological Courses (nine to twelve credits), and (3) Application Courses (six to nine credits). The remaining nine credits may be earned by taking additional graduate courses in system dynamics, mathematics, organizational behavior, finance, economics, etc. Alternatively, up to six

Return to Table of Contents

credits may be earned through project work supervised by a member of the faculty. Students must work with a faculty advisor to create a Plan of Study that must be submitted to the Director of the Graduate Program in System Dynamics during his or her first semester in the program. Students who have previously earned a Graduate Certificate in System Dynamics and wish to continue their studies to the Master level should submit their Plan of Study with their application for admission.

Admission

A student will be eligible to apply for admission into WPI's Master of Science in System Dynamics program if they have earned an undergraduate degree from an accredited college or university. Admission is also open to undergraduate students who are enrolled in WPI's five-year B.S./M.S. program, with the student's undergraduate major being determined by his or her interests. All admission decisions will be made by the Director of WPI's Graduate Program in System Dynamics. He or she will consider all information contained in a student's application including his/her prior academic performance, professional experience, letters of recommendation, etc.

Interdisciplinary Master Degree in Systems Modeling

The term "systems modeling" is not limited specifically to system dynamics modeling. Indeed, other modeling techniques can also be classified under a systems heading. The curriculum embodied in WPI's Master Degree in Systems Modeling blends both system dynamics courses and more traditional mathematical modeling courses to create a broader program embodying a systems or enterprise perspective.

WPI's systems modeling curriculum involves both exact analytical, and numerical (i.e., computer simulation-based), approaches to the construction of mathematical models of complex dynamic socioeconomic, physical, or biological systems. It builds on methods native to a variety of fields such as operations research, control theory, numerical methods, and computer simulation, to establish a broad understanding of the mathematics of systems modeling, which is then applied to a plethora of domains such as management, ecology, economics, and biology. Systems modeling students study the foundations of system dynamics as well as its methodological roots in other disciplines, preparing them to mobilize the concepts they learn to solve real world problems.

Degree Requirements

WPI's Master of Science in Systems Modeling requires thirty credit hours of graduate study (i.e., ten courses). Fifteen credit hours (i.e., five courses) must be earned in the field of system dynamics and fifteen credit hours (i.e., five courses) must be earned in the area of mathematical modeling and/or an application area (e.g., industrial engineering, management, power systems, health care delivery, etc.). Up to six credits from the application area or from mathematical modeling can be earned through project work supervised by an appropriate member of the faculty. Students must work with a faculty advisor to create a Plan of Study that must be submitted to the Director of the Graduate Program in System Dynamics during his or her first semester in the program. Students who have previously earned a Graduate Certificate in System Dynamics and wish to continue their studies to the Master level should submit their Plan of Study with their application for admission.

Admission

A student will be eligible to apply for admission into WPI's Master of Science in Systems Modeling if they have earned an undergraduate degree from an accredited college or university. All admission decisions will be made by the Director of WPI's Graduate Program in System Dynamics. He or she will consider all information contained in a student's application including his/her prior academic performance, professional experience, letters of recommendation, etc.

B.S./M.S. in System Dynamics or System Modeling

The requirements for WPI's Master of Science in System Dynamics and Master of Science in Systems Modeling degrees are designed so that it's possible for WPI undergraduates to pursue a five-year B.S./M.S. program, in which the Bachelor's Degree is awarded in any major offered by WPI and the Master Degree is awarded in either System Dynamics or Systems Modeling.

WPI allows the double counting of up to twelve credits for students pursuing a B.S./M.S. program. This overlap can be achieved in several ways:

- Credits from up to two graduate system dynamics/systems modeling courses may be counted toward meeting WPI's undergraduate social science requirement.
- Credits from up to four graduate system dynamics/systems modeling courses may be counted toward meeting WPI's undergraduate mathematics/engineering/science elective requirement, subject to the approval of the department offering the student's major.
- Credits from up to two 4000-level undergraduate courses taken in a student's major area of study may be counted toward WPI's Master Degree in System Dynamics or Systems Modeling if they can be placed in one of the categories listed in the Degree Requirements for the Master of Science in System Dynamics section or the Degree Requirements for the Master of Science in Systems Modeling section above, and are approved by the Director of WPI's Graduate Program in System Dynamics.
- Up to three graduate credits can be earned by double counting a WPI Interactive Qualifying Project or WPI Major Qualifying Project if it involves substantial use of system dynamics at an advanced level, subject to the approval of the Director of WPI's Graduate Program in System Dynamics.

Interdisciplinary Ph.D. Degree in System Dynamics

WPI's Department of Social Science & Policy Studies offers an interdisciplinary Ph.D. program in system dynamics, in which students work with faculty from the Department of Social Science & Policy Studies and other WPI Ph.D.-granting departments to apply the tools and perspective of system dynamics to challenging problems in a variety of academic disciplines. Working with his or her faculty advisors, a student prepares a Plan of Study, tailored to his or her interests, that includes graduate coursework in system dynamics as well as an area of application. See page 120 for details about individually designed, interdisciplinary Ph.D. degrees.

Doctoral Committee and Plan of Study

Each Plan of Study in WPI's Interdisciplinary Ph.D. Program in System Dynamics is tailored to a student's interests, as well as to those of the participating members of the faculty. The first step in creating a Plan of Study is to assemble an interdisciplinary doctoral program committee. This committee must consist of at least three members of the faculty, with at least one member of the committee drawn from each participating department.

The Plan of Study itself is developed by the student in consultation with his or her doctoral committee. It must outline at least sixty credit hours of graduate work designed to enable the student to do original research involving the application of system dynamics to a challenging problem(s) in a particular domain. The Plan of Study should address the needs and interests of both the student and participating faculty, as well as meet all the requirements for the Ph.D.

Degree Requirements

In addition to meeting WPI's general requirements for a Ph.D., students in the Interdisciplinary Ph.D. Program in System Dynamics must complete four major steps:

1. Submit a Plan of Study approved by his or her doctoral committee to WPI's Office of the Registrar.
2. Pass a qualifying exam prior to completing eighteen credit hours (i.e., six courses) of graduate study. The purpose of this exam is to help the student's doctoral committee ascertain whether or not his or her coursework is on track, given the research agenda outlined in his or her Plan of Study.
3. Pass a dissertation proposal defense. This exam is held after a student has completed his or her course work and prepared a formal dissertation proposal. The purpose of this exam is two-fold. First, to enable the student's doctoral committee to determine whether or not the problem(s) the student has chosen for the dissertation is complex enough to warrant a Ph.D., but not so complex as to be unfinishable in a reasonable amount of time. Second, to enable the student's doctoral committee to determine whether or not the approach to solving the problem(s) the student has proposed is likely to yield new and scientifically valid results if he or she follows the approach correctly. After passing this exam a student is considered to be a Ph.D. Candidate.
4. Pass a dissertation defense. This exam is held after a student has completed his or her dissertation research. The purpose of the exam is to provide the student's doctoral committee with a chance to evaluate the final product in its entirety, as well as to enable the WPI community at large to be exposed to the original work of a new scholar.

Summary of Post-Master Degree Credits

1. *Pre-Qualifying Exam Coursework:* Eighteen credits (i.e., six courses)
2. *Post-Qualifying Exam Coursework:* A minimum of six credits (i.e., a minimum of two courses)
3. *Post-Qualifying Exam/Pre-Candidacy Exam:* A maximum of eighteen dissertation credits
4. *Post Candidacy Exam:* A minimum of twelve dissertation credits.
5. *Additional Graduate Coursework or Dissertation Credits:* As necessary

Note that in order to graduate a student must earn, post-Master degree, a total of at least thirty *dissertation* credits from numbers 3 and 4 above, and a total of at least sixty *graduate* credits from numbers 1-5 above.

Admission

The general admission criteria for WPI's Ph.D. programs are contained on page 9 of this Graduate Catalog. Applicants to the Interdisciplinary Ph.D. Program in System Dynamics must have earned both a bachelor degree and a Master degree from an accredited college or university and take the GRE. The GRE can be waived, however, with the approval of WPI's Graduate System Dynamics Committee.

Course Descriptions

All courses are 3 credits unless otherwise noted.

Fundamental Courses

SD 550. System Dynamics Foundation: Managing Complexity

Why do some businesses grow while others stagnate or decline? What causes oscillation and amplification – the so called "bullwhip" – in supply chains? Why do large scale projects so commonly over overrun their budgets and schedules? This course explores the counter-intuitive dynamics of complex organizations and how managers can make the difference between success and failure. Students learn how even small changes in organizational structure can produce dramatic changes in organizational behavior. Real cases and computer simulation modeling combine for an in-depth examination of the feedback concept in complex systems. Topics include: supply chain dynamics, project dynamics, commodity cycles, new product diffusion, and business growth and decline. The emphasis throughout is on the unifying concepts of system dynamics.

SD 551. Modeling and Experimental Analysis of Complex Problems

This course deals with the hands on detail related to analysis of complex problems and design of policy for change through building models and experimenting with them. Topics covered include: slicing complex problems and constructing reference modes; going from a dynamic hypothesis to a formal model and organization of complex models; specification of parameters and graphical functions; experimentations for model understanding, confidence building, policy design and policy implementation. Modeling examples will draw largely from public policy agendas. (Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity.)

SD 557. Latent Structures, Unintended Consequences, and Policy

This course addresses policy resilience and unintended consequences arising out of actions that are not cognizant of the latent structure causing the problem. An attempt is made to identify the generic systems describing such latent structures. The latent structures discussed include a selection from capacity constraining and capacity enabling systems, resource allocation, and economic cycles of various periodicities. Problems discussed in lessons include pests, gang violence, terrorism, political instability, professional competence in organizations, urban decay, and economic growth and recessions. Students work with selected public policy problems relevant to the generic latent structures discussed in the course. (Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity, SD 551 Modeling and Experimental Analysis of Complex Problems)

Methodological Courses

SD 552. System Dynamics for Insight

The objective of this course is to help students appreciate and master system dynamics' unique way of using of computer simulation models. The course provides tools and approaches for building and learning from models. The course covers the use of molecules of system dynamics structure to increase model building speed and reliability. In addition, the course covers recently developed eigenvalue-based techniques for analyzing models as well as more traditional approaches. (Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems.)

SD 553. Model Analysis and Evaluation Techniques

This course focuses on analysis of models rather than conceptualization and model development. It provides techniques for exercising models, improving their quality and gaining added insights into what models have to say about a problem. Five major topics are covered: use of subscripts, achieving and testing for robustness, use of numerical data, sensitivity analysis, and optimization/calibration of models. The subscripts discussion provides techniques for dealing with detail complexity by changing model equations but not adding additional feedback structure. Robust models are achieved by using good individual equation formulations and making sure that they work together well though automated behavioral experiments. Data, especially time series data, are fundamental to finding and fixing shortcomings in model formulations. Sensitivity simulations expose the full range of behavior that a model can exhibit. Finally, the biggest section, dealing with optimization and calibration of models develops techniques for both testing models against data and developing policies to achieve specified goals. Though a number of statistical issues are touched upon during the course, only a basic knowledge of statistics and statistical hypothesis testing is required. (Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems, or permission of the instructor.)

SD 554. Real World System Dynamics

In this course students tackle real-world issues working with real managers on their most pressing concerns. Many students choose to work on issues in their own organizations. Other students have select from a number of proposals put forward by managers from a variety of companies seeking a system dynamics approach to important issues. Students experience the joys (and frustrations) of helping people figure out how to better manage their organizations via system dynamics. Accordingly the course covers two important areas: consulting (i.e. helping managers) and the system dynamics standard method - a sequence of steps leading from a fuzzy "issue area" through increasing clarity and ultimately to solution recommendations. The course provides clear project pacing and lots of support from the instructors and fellow students. It is recommend that students take SD 552 Real World System Dynamics toward the end of their system dynamics coursework as it provides a natural transition from coursework to system dynamics practice. (Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity and SD 551 Modeling and Experimental Analysis of Complex Problems.)

Applications Courses

SD 556. Strategic Modeling and Business Dynamics

The performance of firms and industries over time rarely unfolds in the way management teams expect or intend. The purpose of strategic modeling and business dynamics is to investigate dynamic complexity by better understanding how the parts of an enterprise operate, fit together and interact. By modeling and simulating the relationships among the parts we can anticipate potential problems, avoid strategic pitfalls and take steps to improve performance. We study a variety of business applications covering topics such as cyclicality in manufacturing, market growth and capital investment. The models are deliberately small and concise so their structure and formulations can be presented in full and used to illustrate principles of model conceptualization, equation formulation and simulation analysis. We also review some larger models that arose from real-world applications including airlines, the oil industry, the chemicals industry and fast moving consumer goods. Students work with selected business policy problems based on generic structures discussed in the lessons. (Prerequisite: SD 550 System Dynamics Foundation: Managing Complexity)

SD 558. Introduction to Agent-Based Modeling

The purpose of this course is to provide students with an introduction to the field of agent-based computer simulation modeling in the social sciences. The course begins with an outline of the history of the field, as well as of the similarities and differences between agent-based computer simulation modeling and system dynamics computer simulation modeling. An important goal of the course is to provide students with guidelines for deciding when it is preferable to apply agent-based modeling, and when it is preferable to apply system dynamics modeling, to a particular problem. Through a series of example models and homework exercises students are introduced to the software that is used in the course. Generally speaking, as the course progresses students will be introduced to increasingly complicated agent-based models and exercises so that their modeling skills will grow. The goal is to increase students' modeling skills so that they will eventually be able to create their own agent-based models from scratch. The remainder of the course is devoted to examining models of socioeconomic phenomena that reside within two broad categories of agent-based models: cellular automata models and multi-agent models. Along the way the cross-category, cross-disciplinary, principles of agent-based modeling (micro-level agents following simple rules leading to macro-level complexity, adaptation, evolving structure, emergence, non-ergodicity) are emphasized.

SD 560. Strategy Dynamics

This course provides a rigorous set of frameworks for designing a practical path to improve performance, both in business and non-commercial organizations. The method builds on existing strategy concepts, but moves substantially beyond them, by using the system dynamics method to understand and direct performance through time. Topics covered include: strategy, performance and resources; resources and accumulation; the 'Strategic Architecture'; resource development; rivalry and the dynamics of competition; strategy, policy and information feedback; resource attributes; intangible resources; strategy, capabilities and organization; industry dynamics and scenarios. Case studies and models are assigned to students for analysis.

SD 561. Energy and Environmental Dynamics

This course helps students develop understanding and proficiency in system dynamics simulation of energy and environmental problems. The majority of the content is devoted to case studies that focus on energy, water and environmental problems. Major business applications deal with boom and bust in power plant construction and a similar pattern of boom and bust in real-estate construction. The text used is: Ford, Andrew. 2009. *Modeling the Environment, 2nd Edition.* Island Press. The book's website (http://www.wsu.edu/~forda/AA2nd.html) provides model files, background on the case studies and a wide variety of extra exercises. For example, Students interested in water resource management can simulate the complex tradeoffs in the management of large river basins; students interested in water quality can experiment with models of accelerated eutrophication of fresh water lakes. A highlight of SD 561 is a class project. One option is to select one of the more challenging sets of exercises from the book (or the book's website). Such a project is often the best way to conclude SD561 for students who are new to system dynamics. The other option is to improve one of the models from the book or the website. This option is usually best for students with previous course work in system dynamics. Their project report will explain why their simulations are an improvement on the published simulations. And they will explain whether the conclusions from their modeling reinforce or contradict the conclusions from the book. (Prerequisite: SD 550 or permission of the instructor).

Return to Table of Contents

SD 562. Project Dynamics

This course will introduce students to the fundamental dynamics that drive project performance, including the rework cycle, feedback effects, and inter-phase "knock-on" effects. Topics covered include dynamic project problems and their causes: the rework cycle and feedback effects, knock-on effects between project phases; modeling the dynamics: feedback effects, schedule pressure and staffing, schedule changes, inter-phase dependencies and precedence; strategic project management: project planning, project preparation, risk management, project adaptation and execution cross project learning; multi-project issues. A simple project model will be created, and used in assignments to illustrate the principles of "strategic project management." Case examples of different applications will be discussed. (Prerequisite: SD 550 System Dynamics Foundation: Managing Complexity.)

SD 565. Macroeconomic Dynamics

There are three parts to this course. The first acquaints a student with dynamic macroeconomic data and the stylized facts seen in most macroeconomic systems. Characteristics of the data related to economic growth, economic cycles, and the interactions between economic growth and economic cycles that are seen as particularly important when viewed through the lens of system dynamics will be emphasized. The second acquaints a student with the basics of macroeconomic growth and business cycle theory. This is accomplished by presenting well-known models of economic growth and instability, from both the orthodox and heterodox perspectives, via system dynamics. The third part attempts to enhance a student's ability to build and critique dynamic macroeconomic models by addressing such topics as the translation of difference and differential equation models into their equivalent system dynamics representation, fitting system dynamics models to macroeconomic data, and evaluating (formally and informally) a model's validity for the purpose of theory selection. (Prerequisites: SD 550 System Dynamics Foundation: Managing Complexity.)

Special Topics

SS 590. Special Topics in Social Science and Policy Studies

(credits: 1-4)

Individual or group studies on any topic relating to social science and policy studies selected by the student and approved by the faculty member who supervises the work. (Prerequisites: permission of the instructor.)

Return to Table of Contents

System Dynamics and Innovation Management

Joint Degree Program – M.S., B.S./M.S. and Graduate Certificate

The program is designed to keep students at the forefront of business innovations by learning the essential principles and techniques of system dynamics and by applying them to critical issues in various business environments. The program prepares students to become part of the next generation of business leaders with competency in understanding internal dynamics of complex human systems so they are equipped with the knowledge, tools and skills to strategically influence decision-making in any organizational or societal setting.

Graduates of this program will be able to:

- Model a complex business decision-making situation to better understand the behavior and identify underlying influential factors so as to provide effective and sustainable innovative ideas as part of vital force of change;
- Synthesize and discern the impact of policies and technological solutions in complex systems across interdisciplinary boundaries;
- Demonstrate visionary leadership and management acumen by acquiring the technical, professional and personal knowledge to transform and/or enhance organizations.

Faculty

Khalid Saeed, Social Science and Policy Studies Department, Director of the Program

Mike Elmes, Foisie School of Business, Co-Director of the Program

All faculty in the Foisie School of Business and in the System Dynamics program are affiliated faculty for the SDIM Program.

Programs of Study

M.S., B.S./M.S. and Graduate Certificate

Admissions Requirements

For M.S. SDIM

Applicants must follow the requirements set forth for all WPI graduate applicants: https://www.wpi.edu/admissions/graduate. Specifically, a bachelor's degree is required in any discipline, along with an acceptable score on either GMAT or GRE examination. The admission decision is made based on the overall profile of an applicant. While there is no specific undergraduate major required, we believe students that will most likely succeed in the program will have had academic training and/or work experience in STEM, social science, economics, or operations research/management.

Degree Requirements

For M.S. SDIM

Students pursuing the M.S. SDIM program must complete a minimum of **33** credits of relevant work at the graduate level. These 33 credits must include either a 3-credit Graduate Qualifying Project or a 9-credit M.S. research thesis depending on the degree requirement option selected, in addition to the coursework requirements described below. These M.S. degree requirements are designed to provide a comprehensive yet flexible program to students who are pursuing an M.S. degree exclusively, as well as students who are pursuing combined B.S./M.S. degrees.

Students accepted into the program will be assigned an academic advisor. In consultation with the academic advisor, a student must prepare a *Plan of Study* outlining the selections that the student will make to satisfy the M.S. degree requirements from among the options offered. This Plan of Study must be submitted to the SDIM Program Review Board for approval no later than a student completes 9 credits.

I. Required Courses (21 credits)

Students in the M.S. SDIM program must take 7 required courses: three from the Social Science & Policy Studies Department and four from the Foisie School of Business as follows:

a) Social Science and Policy Studies Department:

SD 550. System Dynamics Foundation: Managing Complexity

SD 551. Modeling Experimental Analysis of Complex Problems

SD 557. Latent Structures, Unintended Consequences and Public Policy

b) Foisie School of Business:

OBC 505. Teaming and Organizing for Innovation

OIE 501 Designing Operations for Competitive Advantage

MIS 500. Innovating with Information Systems

II. Electives (3-9 credits)

Students must take coursework from the electives listed below in order to satisfy the remainder of the 33 credit program requirement. Those opting to pursue the research thesis option will take 3 credits of electives. Those pursuing GQP option will take 9 credits of electives.

While the required courses ensure that students have adequate coverage of essential SDIM knowledge and skills, the wide variety of electives listed below allows students to tailor their degree program to domains and technical areas of personal interest. Students are expected to select electives to produce a consistent program of study. Other courses beyond the pre-approved program electives listed below may be chosen as electives with *prior* approval by the SDIM Program Review Board. Independent study and directed research credits also require *prior* approval by the SDIM Program Review Board.

Relevant System Dynamics Graduate Courses:

- SD 553: Modeling Analysis and Evaluation Techniques
- SD 554: Real World System Dynamics
- SD 556: Strategic Modeling and Business Dynamics
- SD 560: Strategy Dynamics
- SD 562: Project Dynamics
- SD 565: Macroeconomic Dynamics
- SD 590: Special Topics

III. Graduate Qualifying Project (3 credits)**/Thesis** (9 credits)

Students in the M.S. SDIM program must complete one of the following two options:

- **A 3-credit Graduate Qualifying Project (SDIM 598)**: This project can be done in teams or individually, and will provide a capstone experience in applying system dynamics and innovation management skills to a real-world problem. It may be completed in cooperation with a sponsoring organization or industrial partner, and must be approved and overseen by a faculty member affiliated with the SDIM Program. Project advisor may be different from the academic advisor.
- **A 9-credit Thesis (SDIM 599)**: This option consists of an individual thesis research or development project. Exceptional students that wish to pursue a Ph.D. degree are encouraged to select this option. The thesis will be overseen by a committee of at least 3 faculty members chaired by a member affiliated with the SDIM program. The thesis proposal must be approved by the SDIM Program Review Board and the student's thesis committee before the student can register for the research credits. Students must satisfactorily complete a written thesis and publically present the results.

For the B.S./M.S. Degree

Students can also pursue a B.S./M.S. degree combining any undergraduate major with M.S. in SDIM. Students enrolled in the B.S./M.S. program must satisfy all the program requirements of their B.S. degree as well as all the program requirements of the M.S. in SDIM. They may double count 4000-level courses for up to 12 credits of the 33 credit hours required for the M.S. in SDIM. They may also double count 12 credits of their graduate course credit towards meeting their undergraduate degree requirements. The conversion rate between graduate credits and undergraduate credits is stated in both the undergraduate and graduate catalogues. Thus, 18 undergraduate credits will yield 12 graduate credits and 12 graduate credits will yield 18 undergraduate credits. Minimum grade earned in double counted courses must be B. Students must register for B.S./M.S. credit prior to taking the courses, as an instructor may assign extra work for those taking a course for meeting the requirement of both degrees.

In consultation with the academic advisor, students must prepare a *Plan of Study* outlining the selections they will make to satisfy the B.S./M.S. degree requirements, including the courses that will double count. This *Plan of Study* should be submitted for approval to the SDIM Program Review Board by the end of 1st semester of enrollment into the B.S./M.S. program. Students must consult their advisors and the graduate catalog for making course selections.

For Graduate Certificates

A graduate certificate program in SDIM is also available and requires **six** courses (18 credits) per following lists, which contain the seven SDIM required courses described above: 3 must be the required System Dynamics courses and 3 are selected from the 4 required Business courses.

a) Social Science and Policy Studies Department:

SD 550. System Dynamics Foundation: Managing Complexity

SD 551. Modeling Experimental Analysis of Complex Problems

SD 557. Latent Structures, Unintended Consequences and Public Policy

b) Business: 3 courses selected from the following list

OBC 505. Teaming and Organizing for Innovation

OIE 501. Designing Operations for Competitive Advantage

MIS 500. Innovating with Information Systems

Upon completion of this certificate, students will have a good understanding of how system dynamics can be applied to analyzing real-world problems and interpret the implications on decision-making and innovative processes.

Program Delivery

Students can avail themselves of multiple learning (delivery) formats including on-campus, online, or blended and can pursue their degree either on a part-time or full-time basis.

Systems Engineering

Faculty

Faculty members hold full time positions in a WPI academic department or are adjunct faculty vetted by a WPI academic department head.

M. Amissah, Assistant Teaching Professor; Ph.D., Old Dominion University. Research focus: Model Based Systems Engineering, Systems Architecture, Complexity Science

S. Bhada, Assistant Professor, Systems Engineering; Ph.D., University of Alabama. Modeling based systems engineering (MBSE), engineering education and team mental models.

T. Gannon, Professor of Practice; Ph.D., Stevens Institute of Technology. Information systems engineering, enterprise systems engineering and integration, fault tolerant systems, information and telecommunications technology, systems architecture and design, and systems engineering capstones.

D. Gelosh, Director, Systems Engineering Programs, Ph.D., University of Pittsburgh. Advancing the overall state of practice for systems engineering and professional development, technical leadership, defense acquisition systems, and competency models and frameworks.

J. P. Monat, Professor of Practice; Ph.D., Stanford University. Systems thinking, emergence and self-organization, system optimization, risk management, decision analysis, project management, business practices.

Programs of Study

- Master of Science in Systems Engineering
- Master of Science in Systems Engineering Leadership
- B.S./M.S. Program in Systems Engineering
- Ph.D. in Systems Engineering
- Graduate Certificate in Systems Engineering
- Graduate Certificate in Systems Engineering Fundamentals
- Graduate Certificate in Systems Thinking
- Advanced Certificate in Systems Engineering

WPI offers graduate levels studies in the field of systems engineering leading to a Master of Science as well as graduate level certificates. These programs are designed to exemplify the WPI tradition of theory and practice and incorporate input from engineers currently practicing systems engineering. The programs integrate content from engineering, science, and management. The M.S. degree is designed to provide students with advanced knowledge of engineering systems and management supplemented with a technology focus. The degree of Doctor of Philosophy is conferred on candidates in recognition of high scientific attainments and the ability to conduct original research. Professional employment in a technological field or industry enhances the student's ability to comprehend the scope and magnitude of the complexity of systems engineering.

B.S./M.S. Program

The Master's degree in System Engineering can be earned by undergraduate students who pursue a five year Bachelor's/Master's degree program in which the Bachelor's degree is awarded in any engineering major at WPI and the Master's degree is awarded in Systems Engineering. Students who are not engineering majors but who are math or science majors and have a minor in an engineering area should contact the Systems Engineering office and discuss their plans and goals with a faculty member in the Systems Engineering program.

WPI allows the double counting of up to 12 credits for students pursuing a 5-year Bachelor's-Master's Degree program. This overlap can be achieved through proper academic course planning and with the following recommendations for double counting courses.

- Students should plan to take SYS 501 in their fourth year of undergraduate studies and double count the credit toward the M.S. SE program requirement. (3 credits)
- Students should plan to take MIS 576 in their fourth year of undergraduate studies and double count the credit toward the M.S. SE program requirement. (3 credits)
- To satisfy the SE Depth Requirement, students should plan to double count any approved combination of 4000 or 500 level engineering, science or math courses that total to at least 6 graduate credits. Per WPI policy: (6 credits)
  - acceptable UG courses are awarded 2 graduate credits
  - acceptable G courses are awarded 2 or 3 graduate credits, depending on the course(s) selected.

Admitted SE B.S./M.S. program students must satisfy all of the requirements of their selected B.S. degree and all the program requirements of the SE M.S. degree. Students interested in the M.S. in Systems Engineering by electing the B.S./M.S. option are strongly encouraged to contact the Systems Engineering office for program planning help.

Admissions Requirements

Admission for the Master's degree and graduate certificates is consistent with the admission requirements listed in the Graduate Catalog for a Master of Science degree. Appropriate undergraduate bachelor's degree majors include but are not limited to Computer Science, Electrical Engineering, Mechanical Engineering, Biomedical Engineering, or Computer Engineering from an accredited university. Admission is determined by a review of the application by faculty from both the Electrical & Computer Engineering Department and the Computer Science Department.

All SE program applicants should have at least the following mathematics skills:

- An solid understanding of statistics and probability
- A strong background in general engineering mathematics and linear algebra.

Applicants who are accepted and who are judged to not have an appropriate mathematics background may be required to take a graduate level refresher course in mathematics.

Return to Table of Contents

Graduate Certificate

A graduate certificate provides qualified students with an opportunity to further their studies in an advanced field. Courses are selected from a range of offerings and give a firm foundation in the field of systems engineering.

Systems Thinking Certificate

This certificate program is designed to meet the needs of a variety of corporations and individuals who are interested in systems engineering education but who may have undergraduate degrees in non-engineering disciplines. The Program of Study shown below presents the requirements for the certificate. Inherent in this program of study is sufficient course selection flexibility for students to, if desired and admitted, be able to continue their graduate studies and earn an M.S. degree in Systems Engineering or SSPS/System Dynamics, depending on student interest and background. For more information consult the WPI website.

Program of Study

The Graduate Certificate in Systems Thinking is composed of 18 credits of graduate coursework, selected as follows.

- The program of study must include the following four graduate courses:
  - SYS 501 Concepts of Systems Engineering
  - SYS 540 Introduction to Systems Thinking
  - SD 550 System Dynamics Foundation: Managing Complexity
  - SD 556 Strategic Modeling and Business Dynamics
- The program of study must also include at least two additional graduate courses tailored to the interests of each student or cohort. Course can be selected from graduate courses from the School of Business, Computer Science, Engineering, Mathematics, System Dynamics and Systems Engineering. Suggested courses include the following:

  If depth in SE is desired:
  - SYS 502 Business Practices
  - SYS 512 Requirements Engineering
  - SYS 579D Engineering Dependable and Secure Systems

  If depth in SD is desired:
  - SD 501 Modeling and Experimental Analysis of Complex Problems
  - SD 562 Project Dynamics

  Additional Suggested Courses:
  - MIS 500 Innovating with Information Systems
  - MIS 576 Project Management
  - OBC 505 Teaming and Organizing for Innovation
  - OBC 537 Leading Change
- Programs of study must be reviewed and approved by an SE or SSPS curriculum committee faculty member.

Graduate Certificate in Systems Engineering

Minimum of 17 credits. For more information, please consult the WPI web.

Graduate Certificate in Systems Engineering Fundamentals

12 credits. For more information, please consult the WPI web.

Advanced Certificate in Systems Engineering

The advanced graduate certificate in Systems Engineering consists of six courses, five in systems engineering and one elective. For more information, consult the WPI website.

Degree Requirements

Master of Science in Systems Engineering

Degree Requirements

The Master of Science in Systems Engineering is a ten course (30 credit-hour) degree with an emphasis on systems engineering and management supplemented with a technology focus. Table 1 lists the program degree requirements.

Table 1: Credit distribution for the M.S. in Systems Engineering

Component	Credits
Core Requirement	12
Leadership/Management Requirement	3
Depth Requirement	6
Elective Courses	6
Capstone Experience	3
Total	**30**

Core Requirement (12 credits)

Each student must complete the core of the Systems Engineering degree program which consists of the following four 3-credit graduate systems engineering courses:

- SYS 501 Concepts of Systems Engineering
- SYS 510 Systems Architecture and Design
- SYS 511 Systems Integration, Verification and Validation
- OIE 542 Risk Management and Decision Analysis

Leadership/Management Requirement (3 credits)

Systems engineers need to be aware of, and trained in, managerial methods and practices. Accordingly, each student must also complete one of the following 3-credit graduate courses:

- MIS 576 Project Management
- MIS 582 Information Security Management
- OBC 505 Teaming and Organizing for Innovation
- OBC 506 The Heart of Leadership: Power, Reflection, and Interpersonal Skills
- OIE 554 Global Operations Strategy
- SD 550 System Dynamics Foundation: Managing Complexity
- BUS 546 Managing Technological Innovation

Another leadership/management course may be substituted with the approval of the student's academic advisor.

Depth Requirement (6 credits, excluding capstone course requirement)

To ensure sufficient breadth of knowledge in Systems Engineering, each student must complete a minimum of 18 Systems Engineering graduate credits. In addition to the core required courses noted in the Core Requirement section, each student must complete two additional 3-credit Systems Engineering graduate courses from those listed in Table 2.

Table 2: Current Systems Engineering Graduate Courses Available to Fulfill Depth Requirement

SYS 502	Business Practices
SYS 512	Requirements Engineering
SYS 520	System Optimization
SYS 521	Model-Based Systems Engineering
SYS 540	Introduction to Systems Thinking
SYS 579C	Complex Decision Making
SYS 579D	Engineering Dependable and Secure Systems
SYS 579R	System Reliability Engineering
SYS 579S	System of Systems Engineering

Elective Courses (6 credits)

6 credit hours of elective graduate courses can be selected to meet the specific needs of students and organizations. All elective courses must be approved by the student's faculty advisor and can be selected from courses offered by the following departments and programs: Computer Science (CS), Systems Dynamics (SD), any WPI engineering department or program (such as ECE, BME, ME, ChE, EnvE and RBE), the School of Business, and Mathematics (MA).

Capstone Experience (3 credits minimum)

The capstone experience requirement may be satisfied by an instructor-led systems engineering project (SYS 585 Systems Engineering Capstone Experience), an individual directed research project (SYS 598 Directed Research), or a Master's Thesis (SYS 599 Thesis). The capstone experience must not exceed a total of 9 credits. Students may not transfer credit to satisfy the required capstone experience. The capstone cannot be taken until the student has successfully completed at least 24 credits, including all Core Requirements.

Ph.D. in Systems Engineering

Admissions

Information regarding admissions to graduate programs in general, and Ph.D. programs in particular, is available in the Graduate Catalog (page 9, Admission Information and page 11, Application Information).

The preferred program applicant will have an M.S. in Systems Engineering. Applicants who have earned an engineering M.S. degree but not in Systems Engineering, and who have demonstrated SE work experience, will be considered for admission into the Ph.D. program based on a thorough review of their application material. Applicants possessing an M.S. in Systems Engineering from WPI are not required to submit TOEFL scores or the application fee. The Graduate Record Exam (GRE) is not required for admission, but applicants are strongly encouraged to submit GRE scores.

Acceptability of Credit Applicable to the SE Ph.D.

See graduate catalog (p.12, Acceptability of Credit).

Coursework Requirements

Students must complete 60 or more credits of graduate work beyond the credits required for the Master of Science degree. Of the 60 credits, at least 30 credits must be registered under the designation SYS 699.

The doctoral student must meet two distribution requirements for courses in areas outside of Systems Engineering. The specific courses used to meet the distribution requirements are selected in consultation with a student's Research Advisor.

For the first course distribution requirement, doctorial students must take a minimum of 12 credit hours of approved, thematically-related graduate level courses from a Science (including Computer Science), Mathematics, or Engineering program, excluding Systems Engineering. For the second course distribution requirement, doctoral students must take a minimum of 9 credit hours of approved, thematically-related graduate level courses from a Science (including Computer Science), Mathematics, or Engineering program, excluding Systems Engineering, and different from the area selected to satisfy the first course distribution requirement. Courses which are cross-listed between the Systems Engineering program and the course offerings of another department or program cannot be used to fulfill either of these distribution requirements.

Students who enter the Systems Engineering program with a Master of Science Degree in a Science (including Computer Science), Mathematics or Engineering program, but excluding a Systems Engineering Master of Science degree, will be considered to have completed the first course distribution requirement for 12 credit hours of approved, thematically-related graduate level courses. Students who meet this exception will still be required to complete a minimum of 60 credits of graduate work, including the second course distribution requirement noted above, for the Systems Engineering Ph.D. beyond the credits required for the Master of Science degree.

All doctoral students are required to attend and pass two offerings of the SE graduate seminar courses, SYS 596A (fall semester) and SYS 596B (spring semester). Students may enroll in the graduate seminar course in any combination (e.g. two different semesters, or same semester over two years). Enrollment in the graduate seminars is required even if a student has already enrolled and counted seminar credit as part of an M.S. degree program.

Publications

All SE Ph.D. students are encouraged to submit and present their research results at appropriate academic and/or professional conferences.

Research Advisor and Dissertation Committee Selection

The doctoral student is required to select a Research Advisor or multiple Co-Advisors. In consultation with the Systems Engineering Academic Program Chair, the Research Advisor(s) form a Dissertation Committee for the student prior to scheduling the Ph.D. Qualifying Examination (described below). The following rules apply to the committee membership.

- The committee must consist of at least three faculty members if there is a single Research Advisor (or four faculty members if there are two Research Co-Advisors).
- At least one of the committee members must be a full-time, WPI tenured/tenure-track faculty member.

- At least one of the committee members and the Research Advisor (or one of the Research co-Advisors) must hold an earned doctoral degree.
- At least half of the committee members must be Systems Engineering full-time or Adjunct faculty members.
- At least one committee member must be a faculty member not affiliated with the WPI SE Program, or a recognized subject matter expert from industry.

Once the Dissertation Committee has been established, any changes to that committee must be approved by the Research Advisor(s). Changes to the student's Research Advisor(s) must be approved by the Systems Engineering Academic Program Chair. A completed *Research Advisor(s) and Committee Selection* form must be filed with the Systems Engineering Program prior to taking the Qualifying Examination and each time there is a change to the Research Advisor(s) or Dissertation Committee.

Ph.D. Qualifying Examination

The doctoral student is required to successfully complete the Qualifying Examination no later than 18 credits beyond the M.S. degree. The Qualifying Examination is administered by the SE Academic Program Chair and the student's Dissertation Committee. At the discretion of the SE Academic Program Chair, additional faculty outside of the student's Dissertation Committee may also be invited to participate in the examination.

The Qualifying Examination is intended to be an opportunity to evaluate the student's level of academic preparation and identify any shortcomings in the student's background upon entrance to the Ph.D. program. The format and duration of the examination is at the discretion of the SE Academic Program Chair and Dissertation Committee. The examination may be written and/or oral and may include questions to test the general background of the student as well as questions specific to the student's intended area of research. Other formats for this examination will be acceptable if approved by the SE Academic Program Chair in consultation with the Dissertation Committee and the Research Advisor(s).

The SE Academic Program Chair and Dissertation Committee determine the outcome of the Qualifying Examination (Pass, Repeat, or Fail) and any required remediation intended to address shortcomings identified in the student's background.

- A grade of Fail will result in dismissal from the SE graduate program.
- A grade of Repeat requires the student to retake the examination within one year of the date of the initial Qualifying Examination.
- A grade of Pass is expected to also include a summary of any required remediation including, but not limited to, coursework, reading assignments, and/or independent study.
- The only permissible grades if a student takes the Qualifying Examination a second time are Pass and Fail.

Irrespective of the outcome of the examination, a *Qualifying Examination Completion* form, signed by the SE Academic Program Chair and Dissertation Committee members, must be filed with the Systems Engineering Program upon completion of the examination.

Upon successful completion of the Qualifying Examination, each doctoral student must submit a *Ph.D. Program of Study (PoS)* form with the Systems Engineering Program. The program of study should be completed in consultation with, and signed by, the student's Research Advisor(s) and should include specific course work designed to address any shortcomings identified in the student's background during the Examination.

Upon successful completion of the Ph.D. Qualifying Examination, the student becomes a SE Ph.D. candidate.

Area Examination

The doctoral student is required to pass an Area Examination prior to writing a dissertation. The Area Examination is intended to be an opportunity for the student's Research Advisor(s) and Dissertation Committee members to evaluate the suitability, scope, and novelty of the student's proposed dissertation topic. The format of the Area Examination is at the discretion of the student's Dissertation Committee but will typically include a presentation by the student describing the current state of their research field, their planned research activities, and the expected contributions of their work.

Students are eligible to take the Area Examination after they have successfully completed the Ph.D. Qualifying Examination and at least two semesters of coursework (18 graduate credit hours if part-time) in the graduate program. Failure to successfully complete the Area Examination prior to the end of the student's seventh semester (42 graduate credit hours if part-time) after Ph.D. program matriculation will be considered a failure to make satisfactory academic progress and may result in removal from the program.

The Research Advisor(s) and Dissertation Committee determine the Pass/Fail outcome of the Area Examination. A grade of Fail will result in dismissal from the SE Ph.D. graduate program. A grade of Pass may include recommendations for study or remediation. An *Area Examination Completion* form must be signed by the student's Research Advisor(s) and Dissertation Committee Members and filed with the Systems Engineering program Graduate Secretary upon completion of the Area examination.

Dissertation and Defense

The doctoral student must complete and orally defend publicly a dissertation prepared under the general supervision of the Research Advisor(s). The research described in the dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Research Advisor(s) and Dissertation Committee shall certify the quality and originality of the dissertation research, the satisfactory execution of the dissertation, and the preparedness of the student for the defense of the dissertation. The Graduate Secretary must be notified of a student's defense at least seven days prior to the date of the defense, without exception. The dissertation defense can be scheduled any time after the end of the semester in which the Area Examination was completed.

Residency Requirements

The student must establish residency by being a full-time graduate student for at least one continuous academic year.

Course Descriptions

All courses are 3 credits unless otherwise noted.

SYS 501. Concepts of Systems Engineering

Systems Engineering is a multifaceted discipline, involving human, organizational, and various technical variables that work together to create complex systems. This course is an introduction and overview of the methods and disciplines that systems engineers use to define, develop, and deploy systems. It includes specific integrated examples, projects, and team building exercises to aid in understanding and appreciating fundamental principles. Topics covered include; Introduction to Systems Engineering; Requirements Development; Functional Analysis and Requirements Allocation; System Architecture and System Design; Integration, Verification and Validation; Trade Studies; Systems Analysis, Modeling and Simulation; Specialty Engineering; Risk Management; and Technical Planning and Management. (Prerequisite: an undergraduate degree in engineering or science, or permission of the instructor)

SYS 502. Business Practices

This course introduces students to the business aspects of Systems Engineering (SE) and is designed to help SE professionals integrate Systems Engineering concepts into a professional business practice environment and to improve systems engineers' understanding fundamental business practices and their relationship to systems engineering.

This course will cover how to prepare and evaluate professional quality business plans, project budgets, financial proposals, timelines and technical outlines. This course will also cover topics such as working with stakeholders; understanding competitive advantage and perceived value of systems engineering; various roles of systems engineers from a business practices perspective; contracting for systems engineering services, how systems engineers impact and are impacted by the various corporate operating divisions, and how to ensure quality control. The course will consist of lectures, case studies, class projects and student presentations.

SYS 510. Systems Architecture and Design

This course will study and contrast various important architectural frameworks, representations, tools, and methodologies in order to provide scalable and flexible approaches for enterprises operating in dynamic and complex environments. Enterprise-level system architecting tools will be discussed and demonstrated. At a minimum, the DoDAF, FEAF, Zachman, and TOGAF architectural frameworks will be discussed in depth. Other topics will include analysis of architectural alternatives to meet physical and logical objectives and providing information and systems assurance in an environment that takes people, processes, and technology into account. Modeling tools such as UML/SysML and the use of model-driven architectures will be presented. Validation of the architecture with stakeholders will be discussed. Methods of identifying risks and opportunities associated with the architectural choice will be explored. Practical examples will be included for illustration. (Prerequisite: SYS 501 Concepts of Systems Engineering or another introductory course in Systems Engineering)

SYS 511. Systems Integration, Verification and Validation

This course examines the use of Systems Engineering principles and best practices with respect to systems and systems-of-systems verification and validation (V&V). V&V processes, activities and methods as they apply across the product lifecycle will be examined. Case studies, papers and exercises will be used to examine the success and failure of verification, validation and test processes. Course topics include 1) How early systems engineering activities and solution sets affect integration, verification, validation and test; 2) V&V activities relative to product development phases; 3) Modeling quality, cost, time and risk; 4) Testing and non-testing methods; 5) V&V planning, execution and reporting; 6) Systems integration; and 7) V&V of critical and complex systems. (Prerequisite: SYS 501 Concepts of Systems Engineering)

SYS 512. Requirements Engineering

Requirements drive system definition and development. Properly managed requirements contribute to project success, while poorly defined and poorly managed requirements often lead to project failure. Modern systems are demanding even more attention to proper requirements definition and management. This course provides processes, techniques, and best practices necessary to develop and manage requirements in today's complex environments. (Prerequisite: SYS 501 Concepts of Systems Engineering. Formerly SYS 579R).

SYS 520. System Optimization

This course covers both the principles and practices of system optimization. The course includes both traditional mathematical treatments of optimization (including linear programming, non-linear programming, integer programming, stochastic methods such as Monte-Carlo methods, multi-objective system optimization, data envelope analysis) and practical, hands-on application with many real-world examples and student projects/exercises. Qualitative as well as quantitative approaches will be discussed. The course begins with an introduction and definitions of system, optimization, and system optimization. It then proceeds to explain the traditional mathematical tools and models used in system optimization including location, allocation, scheduling, and blending models as well as sensitivity analysis and network models. Optimized design is covered next. The course will conclude with several multi-objective optimization problems. Student projects and real-world examples will be heavily emphasized. A technical undergraduate degree (B.A. or B.S. or equivalent) is a prerequisite for this course. (Prerequisite: SYS 501.)

SYS 521. Model-Based Systems Engineering

Model-based systems engineering (MBSE) formalizes the practice of systems engineering through the use of models. This course is intended to answer the why, what and how of MBSE and provides background and motivation for transitioning from a document centric approach to a model-based approach to systems engineering. The course provides a foundation for MBSE by introducing SysML as a descriptive language for modeling systems and a method for applying SysML to support the specification, architecture design, and analysis of complex systems. The course also introduces other important aspects of implementing MBSE, including organizational and project planning considerations. The course includes a combination of slide presentations to introduce the fundamentals, coupled with class exercises and a class project to help the student grasp the fundamentals. A modeling tool is expected to be used for the class project. (Prerequisite: SYS 501 Concepts of Systems Engineering.)

SYS 540. Introduction to Systems Thinking

Systems Thinking provides an arsenal of tools that enable program managers and systems engineers to better identify, understand, and control systems, and to improve their performance. In this course, we will study system identification and delineation, causal loops and feedback, system leverage points, delays and oscillations, mental models and unintended consequences, emergent properties, patterns, events, and self-organization, and use these tools to improve the performance of engineering, biological, business, and complex social systems. We will explore great system failures, how they might have been avoided, and how we can learn from them in developing and participating in current systems. Finally, we will learn how systems thinking explains the conflicting behavior of individuals, departments, businesses, and countries.

SYS 579. Special Topics

SYS 585. Systems Engineering Capstone Experience

One of the central priorities in WPI's educational philosophy is the application of academic skills and knowledge to real-world problems. The capstone project represents a substantive evaluation and application of coursework covered in the program. Students are encouraged to select projects with practical significance for the advancement of their company's competitive position as well as their own personal development. The project is administered, advised, and evaluated by WPI as part of the learning experience, but students are encouraged to seek mentorship from experienced colleagues in the Systems Engineering profession. The presence of or degree of participation from a mentor is made at the discretion of the student or the organization sponsoring the program. (Prerequisite: SYS 501 Concepts of Systems Engineering)

SYS 596A and SYS 596B. Graduate Seminars

The graduate seminar series will be presented by recognized experts in various fields of Systems Engineering and related disciplines. All SE Ph.D. students are required to take two offerings of the SE seminar course. Each offering will be graded Pass/Fail.

SYS 597. Independent Study

Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. Independent study students will work under the direct supervision of a WPI ECE, ME or CS faculty member.

SYS 598. Directed Research

Directed research students will work under the direct supervision of a WPI ECE, ME or CS faculty member on an experimental or theoretical problem which may involve an extensive literature search, experimental procedures and analysis. A comprehensive report in the style of a technical report or paper and an oral presentation are required.

SYS 599. Thesis

(Prerequisite: Accepted to Systems Engineering M.S. degree program.)

SYS 699. Ph.D. Dissertation

Reserved for Ph.D. candidate research. Approval of the Ph.D. research advisor is required.

Return to Table of Contents

Index

Academic Standards 13
Admission 9, 10
Advanced Graduate Certificates 5
Aerospace Engineering 27
Application Requirements 11
Applying to WPI 9
Audit 19

Bachelor/Master's Program 4
Biochemistry 69
Bioinformatics and Computational Biology 34
Biology and Biotechnology 37
Biomedical Engineering 42
Bookstore 23
B.S./M.S. 4
Business School of 50

Career Development Center 23
Certificate in Nuclear Science and Engineering 124
Certificate in Power Systems Engineering 103
Certificate in Power Systems Management 123
Chemical Engineering 64
Chemistry and Biochemistry 69
Civil and Environmental Engineering 73
Class Cancellation 23
Collaborative for Entrepreneurship and Innovation 51
Combined Bachelor/Master's Program 4
Commencement Participation Policy 15
Computer Science 80
Computer Security 88
Confirmation of Admission 10
Construction Project Management 74
Corporate and Professional Education 7
Course Changes 18

Data Science 89
Data Science Graduate Course Chart 95
Dean of Graduate Studies 26
Dean of Students 26
Deferred Enrollment 10
Degree Requirements 20
Directions 208
Dissertations 22
Doctor of Philosophy 73
Doctor of Philosophy in Mathematical Sciences 142
Doctor of Philosophy in Statistics 142
Doctor of Philosophy (Ph.D.) 3
Driving Directions 208

Electrical and Computer Engineering 99
Engineering and Construction 74
Enrollment and Registration 16
Environmental Engineering 74

Fellowships 12
Financial Assistance 12
Fire Protection Engineering 112
Foisie School of Business 50

Geotechnical Engineering 74
Gordon Library 24
Grade Appeal 14
Grade Change Policy 14
Grading System 13
Graduate and Advanced Graduate Certificates 5
Graduate Certificate Program 5
Graduate Internship Experience 17
Graduate Programs 2
Graduate Programs by Degree 3

Health Center 23
Health Insurance 19
Housing 25

IELTS 9
Information Technology 52
Information Technology Services 23
Innovation with User Experience 53
Insurance 19
Interactive Media & Game evelopment 115
Interdisciplinary Master's and Doctoral Programs 4
Interdisciplinary Programs 120
International Graduate Student Services 25

Joint Degree Program 199

Late Fees 19
Learning Sciences and Technologies 125
Leave of Absence 16
Library 24

Mail Services 25
Management 53
Manufacturing Engineering 129
Manufacturing Engineering Management 122
Marketing and Innovation 53
Master Builder 74
Master of Business Administration 3, 51
Master of Engineering 3, 74
Master of Mathematics for Educators 3, 142
Master of Science 3
Master of Science and Doctor of Philosophy 73
Master of Science in Mathematics for Educators 3, 142, 191
Master of Science in Physics for Educators 4, 191
Materials Science and Engineering 134

Mathematical Sciences 140
Mechanical Engineering 152
Monthly Payment Option 19
M.S. to Ph.D. 10

Neuroscience 167

Operations Analytics and Management 54

Payment Option 19
Ph.D. 3
Physics 171
Plan of Study 15
Power Systems Engineering 100
Power Systems Management 122
Printing Services 25
Professional Master of Science in Financial Mathematics Program 141
Professional Master of Science in Industrial Mathematics Program 142
Project, Thesis, and Dissertation Advising 15

Registration 16
Research Assistantships 12
Robert A. Foisie School of Business 50
Robotics Engineering 178

School of Business 50
Science and Technology for Innovation in Global Development 187
Sports and Recreation 25
STEM for Educators 191
Structural Engineering 73
Student ID Cards 26
Student Loans 12
Student Services 23
Supply Chain Management 54
System Dynamics 194
System Dynamics and Innovation Management 199
Systems Engineering 201
Systems Thinking Certificate 202

Teaching Assistantships 12
Technology Support and Instruction 24
Theses 22
TOEFL 9
Transcripts 18
Transfers and Waivers 21
Transportation Engineering 74
Tuition Adjustments for Leaves and Withdrawals 19
Tuition and Fees 19
Tuition Payments & Billing 19

WPI Online 8
WPI Police 23

Notice of Disclaimer

WPI reserves the right to make changes in policy, regulations, tuition and fees subsequent to the publication of this material. For a current description of the WPI policies and procedures, tuition and fees, please contact the Graduate Studies and Enrollment Office.

Notice of Nondiscriminatory Policy as to Students

It is the policy of WPI that each qualified individual shall have equal opportunity in education, employment and services at WPI. As a matter of practice and policy, and in accordance with the Civil Rights Act of 1964, Title IX of the Education Amendments of 1972, Section 504 of the Rehabilitation Act of 1973, and other state and federal laws, WPI does not discriminate on the basis of race, color, age, sex, ancestry, religion, national origin, sexual orientation, family status, disability or membership in the armed services, in recruiting and admitting students, awarding financial aid, recruiting and hiring faculty and staff, or in operating any of its programs and activities.

Notice of Accreditation

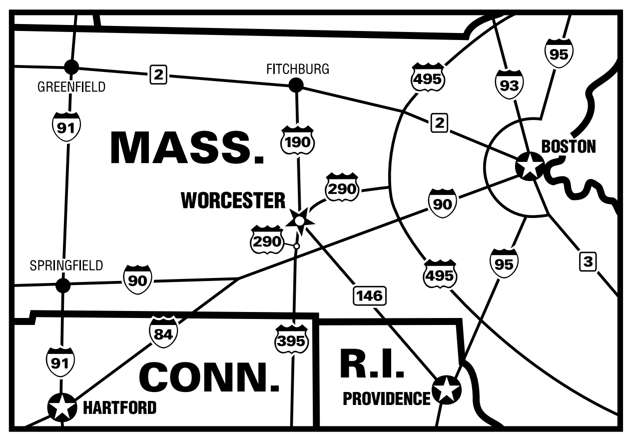
WPI is accredited as an institution by the New England Association of Schools and Colleges Inc., a nongovernmental, nationally recognized organization whose affiliated institutions include elementary schools through collegiate institutions offering post-graduate instruction.

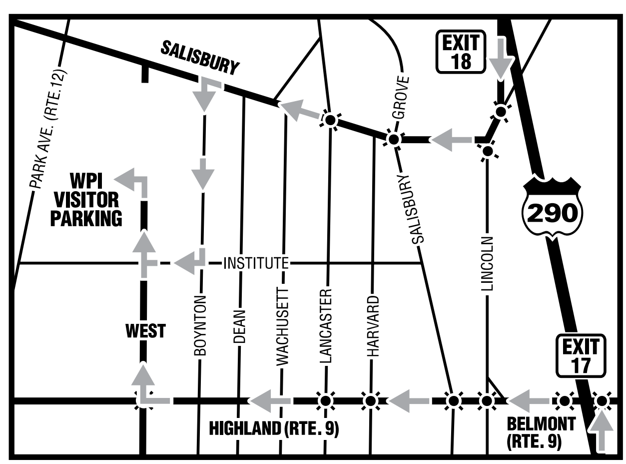
Driving Directions

To WPI's Worcester Campus

100 Institute Road, Worcester, MA

The top map will guide you to I-290. Exit at 17 if eastbound or 18 if westbound. Using the bottom map, follow the arrows to the WPI campus.





Return to Table of Contents

WPI

Graduate Admissions
100 Institute Road
Worcester, MA 01609-2280
Phone: +1-508-831-5301
Fax: +1-508-831-5717
grad@wpi.edu
grad.wpi.edu