# DEPARTMENT AND PROGRAM DESCRIPTIONS

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AEROSPACE ENGINEERING

N.A. GATSONIS, DIRECTOR

PROFESSORS: N. A. Gatsonis, F. Looft, R. Sisson

ASSOCIATE PROFESSORS: J. Blandino, M. Demetriou, N. A. Gatsonis, F. Looft, R. Sisson

ASSISTANT PROFESSORS: I. Hussein, S. Evans, D. Lados

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

1. The graduates of the Aerospace Engineering Program will be successful as:
   a. Aerospace or related engineering professionals in industry or government, and/or
   b. Recipients of graduate degrees in aerospace and related engineering areas or in other professional areas.

2. The graduates of the Aerospace Engineering Program will:
   a. Become successful engineers as a result of their mastery of the fundamentals in mathematics and basic sciences, and as a result of their sound understanding of the technical concepts relevant to aerospace engineering and design.
   b. Become leaders in business and society due to their broad preparation in the effective uses of technology, communication, and teamwork, and due to their appreciation of the importance of globalization, professional ethics, and impact of technology on society.

PROGRAM OUTCOMES

Graduating students should demonstrate that they attain the following:

• an ability to apply knowledge of mathematics, science, and engineering
• an ability to design and conduct experiments, as well as to analyze and interpret data
• an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
• an ability to function on multi-disciplinary teams
• an ability to identify, formulate, and solve engineering problems
• an understanding of professional and ethical responsibility
• an ability to communicate effectively
• the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
• a recognition of the need for, and an ability to engage in lifelong learning
• a knowledge of contemporary issues
• an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
• knowledge covering one of the areas - aeronautical engineering or astronautical engineering - and, in addition, knowledge of some topics from the area not emphasized
• design competence that 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) 4
2. Engineering Science and Design (Includes MQP) (Notes 5,6) 6

NOTES:

1. Must include a minimum of 5/3 units of mathematics including differential and integral calculus, and differential equations.
2. Must include a minimum of 3/3 units in physics including introductory electricity and magnetism, and intermediate mechanics.
3. Must include 1/3 unit in chemistry.
4. Must include 1/3 units in thermodynamics (can be satisfied with CH 3510 as a Mathematics and Basic Science Elective, or other equivalent course with approval of the AE Program Committee)
5. Must include 18/3 units in Engineering Science and Design, distributed as follows:
   a. 12/3 units in Aeronautical Engineering
      i. 3/3 units in Aerodynamics with topics in: incompressible fluid dynamics, compressible fluid dynamics, subsonic and supersonic aerodynamics.
      ii. 2/3 units in Aerospace Materials with topics in: materials science, and aerospace materials.
      iii. 2/3 units in Structures, with topics in: stress analysis, and aerospace structures.
      iv. 2/3 units in Propulsion, with topics in: introductory fluid dynamics, and gas turbine propulsion.
   b. 2/3 units in Flight Mechanics, and Stability and Control, with topics in: control theory, and aircraft dynamics and controls.
   c. 1/3 units in Major Design of a system, component, or process to meet desired needs incorporating appropriate engineering standards and multiple realistic constraints, including the integration of aeronautical topics (fulfilled by ME 4770 Aircraft Design).
### AEROSPACE ENGINEERING PROGRAM CHART

#### 12/3 UNITS OF GENERAL EDUCATION ACTIVITIES

<table>
<thead>
<tr>
<th>Mathematics</th>
<th>Physics</th>
<th>Chemistry</th>
<th>Electives</th>
</tr>
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<tbody>
<tr>
<td>5/3 Units</td>
<td>3/3 Units</td>
<td>1/3 Units</td>
<td>3/3 Units</td>
</tr>
<tr>
<td>MA 1021 Calculus I</td>
<td>PH 1110 or PH 1111 General Physics-Mechanics</td>
<td>CH 1010 Chemistry I or CH 1020 Chemistry II</td>
<td>CH 3510 Thermodynamics (Note 1)</td>
</tr>
<tr>
<td>MA 1022 Calculus II</td>
<td>PH 1120 or PH 1121 General Physics-Elec &amp; Magnet Mechanics I</td>
<td></td>
<td>Courses from the General Category of Mathematics and Basic Science</td>
</tr>
<tr>
<td>MA 1023 Calculus III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MA 1024 Calculus IV</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MA 2051 Ordinary Diff Eqs</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 3/3 UNITS OF FREE ELECTIVE

| 3/3 Units FREE ELECTIVE | See Catalog |

#### 12/3 UNITS OF MATHEMATICS AND BASIC SCIENCE

<table>
<thead>
<tr>
<th>Mathematics</th>
<th>Physics</th>
<th>Chemistry</th>
<th>Electives</th>
</tr>
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<tbody>
<tr>
<td>5/3 Units</td>
<td>3/3 Units</td>
<td>1/3 Units</td>
<td>3/3 Units</td>
</tr>
<tr>
<td>MA 1021 Calculus I</td>
<td>PH 1110 or PH 1111 General Physics-Mechanics</td>
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<tr>
<td>MA 1022 Calculus II</td>
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<td>Courses from the General Category of Mathematics and Basic Science</td>
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<tr>
<td>MA 1023 Calculus III</td>
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<tr>
<td>MA 2051 Ordinary Diff Eqs</td>
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#### 18/3 UNITS OF ENGINEERING SCIENCE AND DESIGN (Note 2)

<table>
<thead>
<tr>
<th>12/3 Units in AERONAUTICAL ENGINEERING</th>
<th>12/3 Units in AERONAUTICAL ENGINEERING</th>
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<tbody>
<tr>
<td>Aerodynamics</td>
<td>Orbital Mechanics and Space Environments</td>
</tr>
<tr>
<td>3/3 Units</td>
<td>1/3 Unit</td>
</tr>
<tr>
<td>ME 3602 Incompressible Fluid Dyn.</td>
<td>ME 2713 Astronautics</td>
</tr>
<tr>
<td>ME 3410 Compressible Fluid Dyn.</td>
<td></td>
</tr>
<tr>
<td>ME 3711 Aerodynamics</td>
<td></td>
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<tr>
<td><strong>Or</strong></td>
<td></td>
</tr>
<tr>
<td>Aerospace Materials</td>
<td>Attitude Determination and Control</td>
</tr>
<tr>
<td>2/3 Units</td>
<td>2/3 Units</td>
</tr>
<tr>
<td>ES 2001 Intro to Materials</td>
<td>ES 3011 Control Engin. I</td>
</tr>
<tr>
<td>ME 4718 Adv. Materials Aerospace Appl.</td>
<td>ME 4713 Spacecraft Dyn. &amp; Controls</td>
</tr>
<tr>
<td><strong>Or</strong></td>
<td></td>
</tr>
<tr>
<td>Structures</td>
<td>Telecommunications</td>
</tr>
<tr>
<td>2/3 Units</td>
<td>1/3 Unit</td>
</tr>
<tr>
<td>ES 2502 Stress Analysis</td>
<td>ME 4733 Guidance, Navigation and</td>
</tr>
<tr>
<td>ME 3712 Aerospace Structures</td>
<td>Communications</td>
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<td><strong>Or</strong></td>
<td></td>
</tr>
<tr>
<td>Propulsion</td>
<td>Space Structures</td>
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<tr>
<td>2/3 Units</td>
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<tr>
<td>ES 3004 Fluid Mechanics</td>
<td>ES 2001 Intro to Materials</td>
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<tr>
<td>ME 4710 Gas Turbines Prop. &amp; Power</td>
<td>ES 2502 Stress Analysis</td>
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<tr>
<td><strong>Or</strong></td>
<td>ME 3712 Aerospace Structures</td>
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<tr>
<td>Flight Mechanics, and Stability and Control</td>
<td>Rocket Propulsion</td>
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<tr>
<td>2/3 Units</td>
<td>4/3 Units</td>
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<td>ES 3011 Control Engin. I</td>
<td>ES 3004 Fluid Mechanics</td>
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<tr>
<td>ME 4723 Aircraft Dyn.&amp; Controls</td>
<td>ME 3602 Incompressible Fluid Dyn.</td>
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<td><strong>Or</strong></td>
<td>ME 3410 Compressible Fluid Dyn.</td>
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<tr>
<td>Major Design Experience</td>
<td>ME 4719 Rocket Propulsion</td>
</tr>
<tr>
<td>1/3 Unit</td>
<td>ME 4771 Spacecraft and Mission Design</td>
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<td>ME 4770 Aircraft Design</td>
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<th>2/3 UNITS IN AERONAUTICAL ENGINEERING</th>
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<tr>
<td>Orbital Mechanics and Space Environments</td>
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<td>ME 2713 Astronautics</td>
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<tr>
<td><strong>Or</strong></td>
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<tr>
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<tr>
<td>Experimentation</td>
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<tr>
<td>1/3 Unit</td>
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<td>Aerospace Design</td>
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<td>3/3 Units</td>
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<tr>
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The courses in the above chart can be replaced by other equivalent courses, with the approval of the AE Program Committee.

**Note 1:** 1/3 unit in Thermodynamics (can be satisfied with CH 3510 as a Mathematics and Basic Science Elective, or other equivalent courses with approval of the AE Program Committee)

**Note 2:** 1/3 unit of an activity must be in Capstone Design (can be satisfied with MQP, ME 4770, or ME 4771)
b. 2/3 units in Astronautical Engineering
   i) 1/3 unit in Orbital Mechanics and Space Environments (fulfilled by ME 2713 Astronautics).
   ii) 1/3 units in Telecommunications (fulfilled by ME 4733 Guidance, Navigation and Communication).
   c. 4/3 units in Aeronautical and Astronautical Engineering
   i. 1/3 unit in Experimentation (fulfilled by ME 3901 Engineering Experimentation).
   ii) 3/3 units in Aerospace Design that involves the design of a system, component, or process to meet desired needs that includes integration of aeronautical and/or astronomical topics (fulfilled by the MQP).

or

a. 12/3 units in Astronautical Engineering
   i. 1/3 unit in Orbital Mechanics, Space Environments (fulfilled by ME2713 Astronautics)
   ii. 2/3 units in Attitude Determination and Control, with topics in: control theory and spacecraft dynamics and controls.
   iii. 1/3 units in Telecommunications (fulfilled by ME4733 Guidance, Navigation and Communication).
   iv. 3/3 units in Space Structures, with topics in: materials, stress analysis, and aerospace structures.
   v. 4/3 units in Rocket Propulsion, with topics in: introductory fluid dynamics, incompressible fluid dynamics, compressible fluid dynamics and, rocket propulsion.
   vi. 1/3 unit in Major Design of a system, component, or process to meet desired needs incorporating appropriate engineering standards and multiple realistic constraints, including the integration of astronomical topics (fulfilled by ME4771 Spacecraft and Mission Design).
   b. 2/3 units in Aeronautical Engineering
   i. 1/3 units in Aerospace Materials (fulfilled by ME4718 Advanced Materials with Aerospace Applications).
   c. 4/3 units in Aeronautical and Astronautical Engineering
   i. 1/3 units in Experimentation (fulfilled by ME3901 Engineering Experimentation).
   ii) 3/3 units in Aerospace Design that involves the design of a system, component, or process to meet desired needs that includes integration of aeronautical and/or astronomical topics (fulfilled by the MQP).
   6. Must include a 1/3 Capstone design activity (fulfilled by ME4770, ME4771 or MQP).

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 a set of requirements and include the integration of aeronautical and/or astronomical engineering topics. MQPs are conducted in 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. (http://www.me.wpi.edu/Aero/mqp.html)

AIR FORCE AEROSPACE STUDIES

LT COL TERENCE A. LEARY, HEAD
PROFESSOR: Lt Col T. Leary
ASSISTANT PROFESSORS: Maj. R. Davis, Capt. D. Richards

MISSION
The mission of AFROTC is to produce leaders for the Air Force and build better citizens for America. Its vision is to be “a highly successful organization, respected throughout the Air Force, the educational community and the nation.”

EDUCATIONAL OBJECTIVES:
Students who successfully complete the AFROTC program will have:
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 two academic years remaining in college may apply for the Two-Year Program. However, there are opportunities for Freshmen, Sophomores, Juniors, and in some cases Seniors and Graduate Students. Please check with the AFROTC Detachment Staff for these special circumstances.

FOUR-YEAR PROGRAM
The more popular and 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 between their sophomore and junior years.

TWO-YEAR PROGRAM
The Two-Year Program is available for college students with two years of undergraduate or graduate study remaining. Applicants must apply for the program no later than the beginning of Term C (spring semester) preceding those two final years. The applicant will take the Air Force Officer Qualifying Test, will be given a physical examination at no expense, and will meet a selection board.
Applicants for the Two-Year Program will attend the Air Force ROTC field training for five weeks instead of four at an Air Force base prior to their entry into the Professional Officer Course (POC). Like their four year counterparts, they are paid while at field training and will receive travel pay to and from the Air Force base hosting field training. Students accepted into the Two-Year Program will complete the Professional Officer Course as described above.

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, to include conducting the Leadership Laboratory itself.

Field Training:
The summer program is designed to develop military leadership, discipline, and to provide Air Force officer orientation and motivation. At the same time, the Air Force can evaluate each student’s potential as an officer. Field training includes aircraft and aircrew orientation, Air Force professional development orientation, marksmanship training, officer training, physical fitness, and survival training. Uniforms, lodging, and meals are provided at no cost to the cadet, and travel at Air Force expense is authorized by air or privately owned vehicle to and from the individual’s home of record or school. Additionally, after applicable deductions, cadets receive pay of about $500 for the four-week encampment and about $625 for the five week summer camp.

Base Visits:
Air Force ROTC officer candidates have the opportunity to visit Air Force bases for firsthand observation of the operating Air Force. These trips are frequently made on weekends or scheduled to coincide with school vacation periods. Officer candidates may be flown by military aircraft or travel by bus to an Air Force base where they spend several days before returning to campus.

Other Benefits:
The Air Force provides all Air Force ROTC uniforms and textbooks for on-campus programs and field training. All officer candidates who have received an Air Force scholarship or are enrolled in the Professional Officer Course (POC) may travel free on military aircraft on a space available basis.

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 Operation Airforce, Space Orientation, and Army Airborne training are also available to selected volunteer officer candidates during the summer.

Arnold Air Society:
Each officer candidate can elect to be part of a national society dedicated to conducting service related events for the Air Force and local community. These Arnold Air Society members are involved in a myriad of service projects to include charity work, service to the poor, work with local orphanages, and similar activities. Twice a year, members participate in conventions/conclaves held in various cities and attended by members from all the schools in the country sponsoring AFROTC. Membership is by nomination after completion of a one semester, project-oriented pledge program.

Civil Air Patrol:
All Air Force ROTC officer candidates at AFROTC Detachment 340 have the opportunity to become members of the Civil Air Patrol and to receive up to 8 flight orientation rides on Civil Air Patrol aircraft at Worcester Regional Airport.

BIOLOGY AND BIOTECHNOLOGY

E. W. OVERSTRÖM, HEAD
PROFESSORS: D. S. Adams, J. C. Bagshaw, E. W. Overström, P. J. Weathers
ASSISTANT PROFESSORS: D. G. Gibson III, L. Mathews, R. Prusty Rao
ADJUNCT AFFILIATE PROFESSOR: A. Di Iorio
ADJUNCT ASSISTANT PROFESSORS/LAB INSTRUCTORS: M. Buckholt, A. Hunter, J. Whitefleet-Smith

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.

PROGRAM EDUCATIONAL OBJECTIVES
The educational objectives of the Department of Biology and Biotechnology are to prepare students to function as scientists and educators in a broad array of biological disciplines. We recognize that the well educated scientist needs facility in technology and skill in critical thinking to function effectively in the professional arena as well as in the global community.

PROGRAM OUTCOMES
Students graduating with a Bachelor of Science degree from the Department of Biology and Biotechnology:

- have mastered a broad range of basic lab skills applicable to biology and biotechnology.

- have mastered applied research skills at an advanced level in at least one area of biology and biotechnology.

- know and understand a broad range of basic biological concepts, and can apply and analyze these in at least one specialty area.
• are able to generate hypotheses, design approaches to test them, and interpret the data from those tests to reach valid conclusions.
• have developed the ability to place their own work in a broader scientific context.
• have developed oral and written communication skills relevant to professional positions in biology and biotechnology.
• can find, read and critically evaluate the original scientific literature.
• possess skills necessary for life-long professional learning.
• can function effectively as members of a team.
• demonstrate adherence to accepted standards of professional and ethical behavior.

Program Distribution Requirements for the Biology and Biotechnology Major

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematical Sciences, Physics, Computer Science, Engineering (Note 1)</td>
<td>5/3</td>
</tr>
<tr>
<td>2. Chemistry</td>
<td>5/3</td>
</tr>
<tr>
<td>3. Biology &amp; Biotechnology (Note 2)</td>
<td>10/3</td>
</tr>
<tr>
<td>4. Laboratory experience (Note 3)</td>
<td>4/3</td>
</tr>
<tr>
<td>5. Related courses (Note 4)</td>
<td>3/3</td>
</tr>
<tr>
<td>6. MQP</td>
<td>1</td>
</tr>
</tbody>
</table>

NOTES:
1. BB 3040 may count toward this requirement.
2. Biology & 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 at the 4000 level. BB 1001 and BB 1002 may not count toward the major requirement. At least 2/3 unit of Biology & Biotechnology coursework must be taken from each of the three major divisions of biology (below). The 2/3 unit for each division may include courses from any level (1000-4000).
3. Chosen from BB 2000/3000 Laboratories or CH 4150 Experimental Biochemistry Laboratory. Must include at least 1/2 unit of course work at the 2000 level.
4. Chosen from the Related Courses List or additional BB 3000/4000 level courses.

THE THREE MAJOR DIVISIONS OF BIOLOGY

1. **Cellular and molecular biology**
   - BB 1035 Introduction to Biotechnology
   - BB 2002 Microbiology
   - BB 2550 Cell Biology
   - BB 2920 Genetics
   - BB 2950 Molecular Biology
   - BB 3055 Microbial Physiology
   - BB 4008 Cell Culture Theory and Applications
   - BB 4010 Advanced Molecular Genetics
   - BB 4065 Virology
   - BB 4550 Advanced Cell 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 and Cell Culture
   - BB 3620 Developmental Biology I
   - BB 363X Developmental Biology II
   - BB 3920 Immunology

3. **Organisms in their environment**
   - BB 1045 Introduction to Biodiversity
   - BB 2030 Plant Diversity
   - BB 2040 Principles of Ecology
   - BB 3140 Evolution: Pattern and Process
   - BB 4150 Environmental Change: Problems and Approaches

**RELATED COURSES**
- BME 4541 Biological Systems
- CE 3059 Environmental Engineering
- CH 2330 Organic Chemistry III
- CH 3510 Chemical Thermodynamics
- CH 4110 Biochemistry I
- CH 4120 Biochemistry II
- CH 4160 Membrane Biophysics
- CH 4190 Regulation of Gene Expression
- CHE 3301 Introduction to Biological Engineering

**OTHER LABORATORY EXPERIENCE LIST**
- BME 562 Small Animal Surgery
- CE 4060 Environmental Engineering Laboratory
- CE 4061 Hydrology
- CH 4150 Experimental Biochemistry
- GE 2341 Geology

**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, the Worcester Biotechnology Research Park, Tufts Cummings School of Veterinary Medicine, and the Woods Hole Marine Biological Laboratories. 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 capstone 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:

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 level BB course</td>
<td>1/3</td>
</tr>
<tr>
<td>2000 level BB courses</td>
<td>2/3</td>
</tr>
<tr>
<td>BB laboratory courses (two 1/6 unit modules; note 1)</td>
<td>1/3</td>
</tr>
<tr>
<td>3000/4000 level BB course</td>
<td>1/3</td>
</tr>
<tr>
<td>4000 level BB course (Capstone)</td>
<td>1/3</td>
</tr>
</tbody>
</table>

NOTE
1. At least one of the BB laboratory courses must be at the 2000 level.

BIOMEDICAL ENGINEERING

K. CHON, HEAD
PROFESSOR: K. Chon, C. H. Sotak
ASSOCIATE PROFESSORS: K. L. Billiar, Y. Mendelson, G. D. Pins
ASSISTANT PROFESSORS: G. R. Gaudette, M. W. Rolle
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.

PROGRAM EDUCATIONAL OBJECTIVES
The educational objectives of the Biomedical Engineering Department, which closely embraces the WPI educational philosophy, are to prepare professionals who can apply fundamental knowledge of engineering and basic science to solve problems in biology and medicine and can engage in a lifetime of professionalism and learning.

PROGRAM OUTCOMES
The Biomedical Engineering Department has established 13 educational outcomes in support of our department objectives. These general and specific program criteria indicated below in parentheses meet the requirements for Biomedical Engineering accreditation by ABET (the Accreditation Board for Engineering and Technology). Accordingly, students graduating from the Biomedical Engineering Department will demonstrate:

1. An ability to apply knowledge of advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology.
2. An ability to design and conduct experiments, as well as to analyze and interpret data from living and non-living systems.
3. An ability to design a system, component, or process to meet desired needs.
4. An ability to function on multi-disciplinary teams.
5. An ability to identify, formulate, and solve engineering problems.
6. An understanding of professional and ethical responsibilities.
7. An ability to communicate effectively.
8. The broad education necessary to understand the impact of engineering solutions in a global and societal context.
9. A recognition of the need for, and an ability to engage in life-long learning.
10. A knowledge of contemporary issues.
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
13. 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. Studying and solving medical and biological problems through analytical techniques in engineering;
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:

<table>
<thead>
<tr>
<th>BIOMEDICAL ENGINEERING</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics (See Note 1)</td>
<td>2</td>
</tr>
<tr>
<td>2. Basic Science (See Note 2)</td>
<td>2</td>
</tr>
<tr>
<td>3. Supplemental Science (See Note 3)</td>
<td>2/3</td>
</tr>
<tr>
<td>4. Laboratory experience with living systems (See Note 4)</td>
<td>1/3</td>
</tr>
<tr>
<td>5. Biomedical Engineering and Engineering (See Note 5)</td>
<td>4 1/3</td>
</tr>
<tr>
<td>6. MQP (See Note 6)</td>
<td>1</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Mathematics must include differential and integral calculus, differential equations and statistics.
2. Two courses from each of the following areas: BB, CH and PH.
3. Two courses from BB, CH or PH.
4. Experimental Physiology (e.g., BME 3111) or equivalent.
5. Thirteen courses from Biomedical Engineering (BME) or Engineering (CE, CHE, ECE, ES, ME, or RBE) as specified in the WPI Catalog “Courses Qualifying for Engineering Department Areas” with the following distribution: (1) seven courses from Biomedical Engineering or Engineering, one of which must be an engineering design course; (2) four courses from Biomedical Engineering or Engineering at the 3000-level or above; (3) two courses in Biomedical Engineering at the 4000-level or above. A minimum of eight of the thirteen courses must be from Biomedical Engineering.
6. Must include 1/3 unit Capstone Design Experience.

### 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, five specializations have been defined: Biomaterials, Biomechanics, Biomedical Imaging, Biomedical Sensors and Instrumentation, 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.

### 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 comes 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.
- Design and manufacturing of replacements parts for damaged or diseased tissues and organs (e.g., artificial hip joints, kidney dialysis machines)

### BIOMEDICAL ENGINEERING PROGRAM CHART

<table>
<thead>
<tr>
<th>FRESHMAN/SOPHOMORE</th>
<th>JUNIOR</th>
<th>SENIOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mathematics (6 courses)</strong></td>
<td>IQP</td>
<td>MQP</td>
</tr>
<tr>
<td>MA 1021 (Calculus I)</td>
<td>Biomedical Engineering (2 courses)</td>
<td></td>
</tr>
<tr>
<td>MA 1022 (Calculus II)</td>
<td>BME 3300 (BME Design)</td>
<td></td>
</tr>
<tr>
<td>MA 1023 (Calculus III)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biology (2 courses)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BB 2550 (Cell Biology)</td>
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<td></td>
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<tr>
<td>BB 3102 (Physiology; Transport and Maintenance)</td>
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<td></td>
</tr>
<tr>
<td><strong>Chemistry (2 courses)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH 1010 (Molecularity)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH 1020 (Forces and Bonding)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Physics (2 courses)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH 1110 (Physics I)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PH 1120 (Physics II)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Supplemental Science (2 courses)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pick 2 from BB, CH, or PH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(See suggested courses from specialization areas listed below)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Biomedical Engineering (select 3 courses)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BME 1001 (Intro. to Bio. Med. Eng.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BME 2204 (Bioelectric Foundations)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BME 2504 (Foundations in Biomechanics)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BME 2604 (Foundations in Biol. Transport)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>H&amp;A Requirement (2 Units)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social Science</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical Education</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DEGREE REQUIREMENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>H&amp;A Requirement (2 units)</td>
<td>IQP (1 unit)</td>
</tr>
<tr>
<td>Math/Science (4 units)</td>
<td>MQP (1 unit)</td>
</tr>
<tr>
<td>Supplemental Science (2/3 Unit)</td>
<td>Biomedical and other Engineering Topics (13/3 Units)</td>
</tr>
<tr>
<td></td>
<td>Living Systems Lab (1/3 Unit)</td>
</tr>
<tr>
<td></td>
<td>Social Science (2/3 Units)</td>
</tr>
<tr>
<td></td>
<td>Free Electives (2/3 Unit)</td>
</tr>
<tr>
<td></td>
<td>Physical Education (1/3 Units)</td>
</tr>
</tbody>
</table>

Note: The total minimum number of BME courses is eight (8)

From the biomedical engineering specialization areas listed below, select nine (9) courses from BME or other engineering disciplines (four of these courses must be at the 3000-level or above, and must include two BME courses at the 4000-level or above).
• 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 mammaplasty, 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)

**Suggested Course Table and Sequence**

<table>
<thead>
<tr>
<th>Supplemental Science (Select two courses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select two from the following science courses below:</td>
</tr>
<tr>
<td>BB 2901 - Molecular Biology, Microbiology, and Genetics</td>
</tr>
<tr>
<td>BB 2902 - Enzymes, Proteins, and Purification</td>
</tr>
<tr>
<td>BB 2903 - Anatomy and Physiology</td>
</tr>
<tr>
<td>BB 3101 - Human Anatomy &amp; Physiology: Movement and Communication</td>
</tr>
<tr>
<td>BB 4008 - Cell Culture Theory and Application</td>
</tr>
<tr>
<td>CH 2310 - Organic Chemistry I</td>
</tr>
<tr>
<td>CH 4110 - Biochemistry I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engineering (Select nine courses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select three fundamental engineering courses, preferred choices include:</td>
</tr>
<tr>
<td>ES 2001 - Introduction to Materials Science</td>
</tr>
<tr>
<td>ES 2501 - Introduction to Static Systems</td>
</tr>
<tr>
<td>ES 2502 - Stress Analysis</td>
</tr>
<tr>
<td>ME 2820 - Materials Processing</td>
</tr>
<tr>
<td>Select two 3000-level (or higher) engineering courses, preferred choices include:</td>
</tr>
<tr>
<td>ES 3001 - Introduction to Thermodynamics</td>
</tr>
<tr>
<td>ES 3004 - Fluid Mechanics</td>
</tr>
<tr>
<td>ME 3501 - Continuum Mechanics (Cat. II)</td>
</tr>
<tr>
<td>ME 4821 - Plastics (Cat. II)</td>
</tr>
<tr>
<td>Select four 3000- and 4000-level BME courses, preferred choices include:</td>
</tr>
<tr>
<td>BME/ME 4606 - Biofluids (Cat. II)</td>
</tr>
<tr>
<td>BME/ME 4814 - Biomaterials</td>
</tr>
<tr>
<td>BME 4828 - Biomaterials-Tissue Interactions</td>
</tr>
<tr>
<td>BME/ME 550 - Tissue Engineering (Cat. II)</td>
</tr>
<tr>
<td>BME 531 - Biomaterials in the Design of Medical Devices</td>
</tr>
</tbody>
</table>

Note #1: At least 2 of the BME courses must be at the 4000-level or above. Graduate level courses can substitute for 4000-level courses.

**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 but many other aspects are included in this diverse field of study including:

• **Dynamics** – analysis of human movement including walking, running, and throwing.
• **Statics** – 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.
• **Fluid mechanics** – analysis flow of blood through arteries and air through the lung.

Biomechanics research has improved our understanding of, among other things:

• 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).

**Suggested Course Table and Sequence**

<table>
<thead>
<tr>
<th>Supplemental Science (Select two courses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select two from the following science courses below:</td>
</tr>
<tr>
<td>BB 2903 - Anatomy and Physiology</td>
</tr>
<tr>
<td>BB 3101 - Human Anatomy &amp; Physiology: Movement and Communication</td>
</tr>
<tr>
<td>BB 3102 - Human Anatomy &amp; Physiology: Transport and Maintenance</td>
</tr>
<tr>
<td>PH 2510 - Atomic Force Microscopy</td>
</tr>
<tr>
<td>CH 2310 - Organic Chemistry I</td>
</tr>
<tr>
<td>CH 4110 - Biochemistry I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Engineering (Select nine courses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Select three fundamental engineering courses, preferred choices include:</td>
</tr>
<tr>
<td>ES 2001 - Introduction to Materials Science [Note #2]</td>
</tr>
<tr>
<td>ES 2501 - Introduction to Static Systems [Note #4]</td>
</tr>
<tr>
<td>ES 2502 - Stress Analysis [Note #2 and Note #4]</td>
</tr>
<tr>
<td>ES 2503 - Introduction to Dynamic Systems [Note #4]</td>
</tr>
<tr>
<td>Select two 3000-level (or higher) engineering courses, preferred choices include:</td>
</tr>
<tr>
<td>ES 3001 - Introduction to Thermodynamics</td>
</tr>
<tr>
<td>ES 3003 - Heat Transfer</td>
</tr>
<tr>
<td>ES 3004 - Fluid Mechanics [Note #3]</td>
</tr>
<tr>
<td>ES 3011 - Control Systems</td>
</tr>
<tr>
<td>ES 3323 - Advanced Computer Aided Design</td>
</tr>
<tr>
<td>ME 3310 - Kinematics of Mechanisms</td>
</tr>
<tr>
<td>ME 3501 - Elementary Continuum Mechanics (Cat. II) [Note #4]</td>
</tr>
<tr>
<td>ME 3506 - Rehabilitation Engineering</td>
</tr>
<tr>
<td>ME 4512 - Introduction to Finite Element Method</td>
</tr>
<tr>
<td>Select four 3000- and 4000-level BME courses, preferred choices include:</td>
</tr>
<tr>
<td>BME/ME 3501 - Elementary Continuum Mechanics (Cat. II) [Note #1]</td>
</tr>
<tr>
<td>BME/ME 3504 - Experimental Biomechanics</td>
</tr>
<tr>
<td>BME/ME 4504 - Biomechanics (Cat. II)</td>
</tr>
<tr>
<td>BME/ME 4606 - Biofluids (Cat. II)</td>
</tr>
<tr>
<td>BME/ME 4814 - Biomaterials</td>
</tr>
<tr>
<td>BME/ME 552 - Tissue Mechanics (Cat. II)</td>
</tr>
<tr>
<td>BME/ME 550 - Tissue Engineering (Cat. II)</td>
</tr>
<tr>
<td>BME/ME 554 - Composites with Biomedical and Materials Applications</td>
</tr>
</tbody>
</table>

Note #1: At least 2 of the BME courses must be at the 4000-level or above. Graduate level courses can substitute for 4000-level courses.
Note #2: These courses should be completed before taking BME 4814.
Note #3: This course should be completed before taking BME 4814.
Note #4: This course should be completed before taking BME 4504 or BME 552.
Biomedical imaging is a broad specialization within biomedical engineering that involves the application of quantitative science and engineering to detect and visualize biological processes. An important sub-area in biomedical imaging is the application of these tools and knowledge 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 imaging:

- Includes the numerous and diverse imaging technologies that nearly cover the electromagnetic spectrum. Examples include x-ray imaging, visible light (optical) imaging, near-infrared imaging, magnetic resonance imaging, and ultrasound imaging. The detected radiation can be either naturally emitted by the body (such as infrared radiation) or re-emitted radiation (as in magnetic resonance imaging). It also includes technologies that produce images following the introduction of a chemical agent into the body, such as nuclear medicine imaging and luminescence-based imaging.

- Involves the development of sophisticated instrumentation to acquire and process images from the body, most often in a non-invasive or minimally-invasive manner. A biomedical engineer is not simply a user of an imaging technology, but an active participant in the development of new technologies.

- Requires an understanding of how energy interacts with biological tissue and how this interaction is used to produce images of diagnostic utility. This understanding is rooted in the disciplines of physics, chemistry, and biology. A biomedical engineer, therefore, must have a strong background in the physical sciences.

- Involves both image acquisition and image processing. Rarely are the signals acquired by the instrumentation immediately interpretable. For example, image processing is used to create two- and three-dimensional images from the acquired "raw" signals and to extract important image features. An example is computed tomography, which converts a series of through-body x-ray images into a cross-sectional image that reveals internal tissue structures. Image processing is grounded in the disciplines of mathematics and computer science.

- Is capable of generating much more than simple anatomic images. For example, newer biomedical imaging technologies are being used to image and quantify blood flow and metabolic activity in normal and diseased tissue. The development of these "functional" imaging technologies has tremendous potential to substantially advance our understanding of biological and disease processes. Because it is often completely non-invasive, biomedical imaging is already revolutionizing the study of brain function in humans.

- Involves all size scales, from sub-cellular to whole body.

- Is an important component of many other disciplines and specializations, including biology and tissue engineering. Without the technical advances in biomedical imaging, we would often be at the mercy of time-consuming and tedious chemical or histological analyses to probe cellular function and microscopic structures. Non-invasive methods also allow biological processes to be studied over time on the same sample.

### Suggested Course Table and Sequence

#### Supplemental Science (Select two courses)
- CH 1040 - Chemistry IV (Dynamics)
- CH 4110 - Biochemistry
- PH 1140 - Oscillations and Waves
- PH 2501 - Photonics
- PH 2601 - Photonics Laboratory

#### Engineering (Select nine courses)
- Select three fundamental engineering courses; preferred choices include:
  - ECE 2111 - Fundamentals of Electrical Circuits
  - ECE 2112 - Electromagnetic Fields
  - ECE 2311 - Continuous-Time Signal and System Analysis
  - ECE 2312 - Discrete-Time Signal and System Analysis
- Select two 3000-level (or higher) engineering courses; preferred choices include:
  - ECE 3113 - Introduction to RF Circuit Design
  - ECE 3204 - Microelectronic Circuits II
  - ME 4922 - Theory and Practice of Laser Instrumentation
- Select four 3000- and/or 4000-level BME courses; preferred choices include [Note #1]:
  - BME/ECE 3011 - Biomedical Signal Analysis
  - BME/ECE 4011 - Biomedical Imaging
  - BME 4201 - Biomedical Imaging
  - BME 581 - Medical Imaging Systems
  - BME 582 - Principles of In Vivo Nuclear Magnetic Resonance Imaging

Note #1: At least 2 of the BME courses must be at the 4000-level or above. Graduate level courses can substitute for 4000-level courses.

### Biomedical Engineering

Modern health care relies heavily on a large array of sophisticated medical instrumentation 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 instrument used to do a variety of small tasks to the desk-top microcomputer needed to process the large amount of clinical information acquired from patients.

A biomedical engineer is not simply a user of measurement technology, but an active participant in the development of new diagnostic and therapeutic modalities. Hence, the Biosensors and Bioinstrumentation track of our program focuses on training students to design, test, and use sensors and biomedical
instrumentation in humans and animals 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 new sensors and advanced measurement devices. This track provides an excellent training experience that prepares students for careers in industry, higher education as well as medical school.

Examples of common biomedical sensors, devices, and instrumentation developed by biomedical engineers and used routinely in medicine include:

- Blood chemistry sensors
- Specialized instrumentation for genetic testing
- Physical sensors (e.g. pressure, temperature, flow)
- Electrical sensors (e.g. electrodes)
- Electrocardiographs (a device that measures the electrical activity of the heart)
- Electroencephalograph (a device that measures the electrical activities of the brain)
- Electromyography (a device that measures the electrical activities of muscles)
- Mechanical respirator
- Cardiac pacemaker
- Defibrillators
- Artificial heart
- Pulse oximeters
- Ultrasonic equipment
- Imaging scanners (nuclear cameras, CAT, MRI)
- Drug infusion and insulin pumps
- Electrosurgical equipment
- Heart-lung machine
- Anesthesia machine
- Kidney dialysis machine
- Specialized equipment used by disabled people (e.g. hearing aids)
- Laser systems for eye surgery

### 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 stimuli on the growth and development of bioengineered cells, tissues and organs. Measure the biomechanical properties of bioengineered tissues and organs.
- 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.

### Suggested Course Table and Sequence

#### Supplemental Science (Select two courses)

<table>
<thead>
<tr>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>BB 2901 - Molecular Biology, Microbiology, and Genetics</td>
</tr>
<tr>
<td>BB 2902 - Enzymes, Proteins, and Purification</td>
</tr>
<tr>
<td>BB 2903 - Anatomy and Physiology</td>
</tr>
<tr>
<td>BB 3101 - Human Physiology: Movement and Communication</td>
</tr>
<tr>
<td>PH 1130 - Introduction to 20th Century Physics</td>
</tr>
<tr>
<td>PH 1140 - Oscillations and Waves</td>
</tr>
<tr>
<td>PH 2501 - Photonics</td>
</tr>
</tbody>
</table>

#### Engineering (Select nine courses)

Select three fundamental ECE courses; preferred choices include:

<table>
<thead>
<tr>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 2011 - Introduction to Electrical and Computer Engineering</td>
</tr>
<tr>
<td>ECE 2022 - Introduction to Digital Circuits &amp; Computer Engineering</td>
</tr>
<tr>
<td>ECE 2111 - Fundamentals of Electrical Circuits</td>
</tr>
<tr>
<td>ECE 2201 - Microelectronic Circuits I</td>
</tr>
<tr>
<td>ECE 2311 - Continuous-Time Signal and System Analysis</td>
</tr>
<tr>
<td>ECE 2312 - Discrete-Time Signal and System Analysis</td>
</tr>
<tr>
<td>ECE 2799 - Electrical &amp; Computer Engineering Design</td>
</tr>
<tr>
<td>ECE 2801 - Foundations of Embedded Computer Systems</td>
</tr>
</tbody>
</table>

Select two 3000-level (or higher) engineering courses; preferred choices include:

<table>
<thead>
<tr>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES 3011 - Control Engineering</td>
</tr>
<tr>
<td>ECE 3204 - Microelectronic Circuits II</td>
</tr>
<tr>
<td>ECE 3801 - Advanced Logic Design</td>
</tr>
<tr>
<td>ECE 3803 - Microprocessor System Design</td>
</tr>
<tr>
<td>ECE 4703 - Real-Time Digital Signal Processing</td>
</tr>
</tbody>
</table>

Select four 3000- and/or 4000-level BE courses; preferred choices include:

<table>
<thead>
<tr>
<th>Course</th>
</tr>
</thead>
<tbody>
<tr>
<td>BME/ECE 3011 - Bioinstrumentation and Biosensors</td>
</tr>
<tr>
<td>BME/ECE 4011 - Biomedical Signal Analysis</td>
</tr>
<tr>
<td>BME 4023 - Biomedical Instrumentation I</td>
</tr>
</tbody>
</table>

Note #1: At least 2 of the BE courses must be at the 4000-level or above. Graduate level courses can substitute for 4000-level courses.
Suggested Course Table and Sequence

Supplemental Science (Select two courses)
Select two from the following science courses below:
BB 2901 - Molecular Biology, Microbiology, and Genetics
BB 2902 - Enzymes, Proteins, and Purification
BB 2903 - Anatomy and Physiology
BB 3101 - Human Physiology: Movement and Communication
BB 4008 - Cell Culture Theory and Application
CH 2310 - Organic Chemistry I
CH 4110 - Biochemistry I
CH 4550 - Polymer Chemistry (cat. II)

Engineering (Select nine courses)
Select three fundamental engineering courses, preferred choices include:
ES 2001 - Introduction to Materials Science
ES 2501 - Introduction to Static Systems
ES 2502 - Stress Analysis
ES 2503 - Introduction to Dynamic Systems
Select two 3000-level (or higher) engineering courses, preferred choices include:
ES 3001 - Introduction to Thermodynamics
ES 3002 - Mass Transfer
ES 3003 - Heat Transfer
ES 3004 - Fluid Mechanics
ME 4821 - Plastics (Cat. II)
Select four 3000- and 4000-level BME courses, preferred choices include:
BME/ME 4814 - Biomaterials
BME/ME 4606 - Biofluids (cat. II)
BME 531 - Biomedical Engineering

Note #1: At least 2 of the BME courses must be at the 4000-level or above. Graduate level courses can substitute for 4000-level courses.

MISSION STATEMENT
The Department of Chemical Engineering at WPI is dedicated to providing excellent education to undergraduate and graduate students in chemical engineering, and to vigorously pursuing discovery, creation, and dissemination of knowledge at the frontiers of chemical engineering. Chemical engineers are uniquely positioned to continue to contribute to the betterment of society through advancements in new materials, biomedicine, alternative energy, transportation, environmental pollution abatement, resource conservation, and sustainable development.

The Department aspires to contribute to this vision by achieving national distinction in selected areas of scholarly inquiry and by educating men and women to become leaders in industrial practice, civil service, education, and research. The Department strives to produce technically competent and socially aware chemical engineers through project-based, innovative, and rigorous educational programs that promote global and societal awareness, innovative thinking, and life-long learning skills.

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.

1. To educate students in the fundamental principles of chemical engineering.
2. To help students develop the ability to use chemical engineering principles to solve problems of practical importance to society.
3. To help prepare students, through broad education, for a lifetime of success as productive and informed members of society as well as of their professional community.
4. To help students become effective communicators.

PROGRAM OUTCOMES
The Chemical Engineering Department has established fifteen educational outcomes in support of our objectives. The outcomes are grouped under the objectives that they support.

Objective 1

1.1 Chemical engineering graduates will possess a working knowledge of the fundamentals of chemistry, physics, and mathematics, including knowledge of advanced elective science subjects such as organic and inorganic chemistry, material science, and biochemistry, etc.
1.2 Chemical engineering graduates will possess a working knowledge of conservation principles and their applications, physical and chemical equilibria, transport and rate processes, separation processes, chemical process control, and reaction engineering.

Objective 2

2.1 Chemical engineering graduates will be able to formulate, analyze, and solve practical chemical engineering problems.
2.2 Chemical engineering graduates will be able to design experiments, safely gather and analyze data, and apply the results to address practical chemical engineering problems.
2.3 Chemical engineering graduates will be able to use appropriate mathematical concepts and methods to solve chemical engineering problems.
2.4 Chemical engineering graduates will be able to design a chemical system, process, or component with consideration of realistic constraints including practical, economic, environmental, safety, ethical, social, and political implications.
2.5 Chemical engineering graduates will be able to use comput ers effectively for solving chemical engineering problems.
Objective 3
3.1 Chemical engineering graduates will be able to function and work effectively alone and in a team environment, including multidisciplinary teams.
3.2 Chemical engineering graduates will possess an appreciation of professional, ethical, and contemporary issues, and the societal and global impact of chemical engineering processes.
3.3 Chemical engineering graduates will possess self-learning skills to ensure life-long learning.
3.4 Chemical engineering graduates will possess an appreciation for the humanities and social sciences.
3.5 Chemical engineering graduates will be able to use their chemical engineering education to serve the chemical engineering profession or a related profession or pursue advanced studies.
3.6 Chemical engineering graduates will have selected technical elective courses, concentrations, projects, and minors that satisfy their professional interest or career goals.

Objective 4
4.1 Chemical engineering graduates will be able to write coherent, concise, and accurate technical reports.
4.2 Chemical engineering graduates will be able to make concise and effective oral presentations.

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.

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics and Base Science (Notes 1 and 2)</td>
<td>4</td>
</tr>
<tr>
<td>2. Engineering Science and Design (Notes 3 and 4)</td>
<td>6</td>
</tr>
<tr>
<td>3. Advanced Chemistry and Natural Science (Note 5)</td>
<td>5/3</td>
</tr>
</tbody>
</table>

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.
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.
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: Biochemical, Biomedical, Environmental, or Materials.

CHEMICAL ENGINEERING WITH BIOCHEMICAL CONCENTRATION
Basic Science:
Any BB course. No more than one 1000 level course may be counted, however. Recommended courses include:
- BB 2002 Microbiology
- BB 3055 Microbial Physiology
- BB 4008 Cell Culture Theory and Applications
- BB 4070 Separation of Biological Molecules
- BB 560 Separation of Biological Molecules

Engineering Science and Design:
- BB 509 Scale-Up of Bioprocessing
- CHE 3301 Introduction to Biological Engineering
- CHE 521 Biochemical Engineering
- BME 1001 Introduction to Biomedical Engineering

Advanced Chemistry:
- CH 4110 Biochemistry I
- CH 4120 Biochemistry II
- CH 4130 Biochemistry III
- BB 4910 Advanced Molecular Biology

CHEMICAL ENGINEERING WITH BIOMEDICAL CONCENTRATION
Basic Science:
(at most, one of these three)
- BB 1035 Introduction to Biotechnology
- BB 2550 Cell Biology
- BB 1025 Human Biology
- BB 3102 Human Anatomy & Physiology: Transport and Maintenance
- BB 4065 Virology

Engineering Science and Design:
- BME 1001 Introduction to Biomedical Engineering
- BME 2604 Foundations in Biological Transport Phenomena
- BME/ME 4504 Biomechanics
- BME/ME 4606 Bioluids
- BME/ME 4814 Biomaterials
- CHE 3301 Introduction to Biological Engineering

CHEMICAL ENGINEERING WITH ENVIRONMENTAL CONCENTRATION
Basic Science:
- GE 2341 Geology
- 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
- CE 3059 Environmental Engineering
- CE 3070 Introduction to Urban and Environmental Planning
- CE 3074 Environmental Analysis
- CE 3060 Water Treatment
- CE 3061 Waste Water Treatment
- CE 4060 Environmental Engineering Lab
- CE 4061 Hydrology

(at most, one of these three)
CHEMICAL ENGINEERING WITH MATERIALS
CONCENTRATION

Engineering Science and Design:
CHE 3601 Chemical Materials Engineering
ES 2001 Introduction to Material Science
CHE 508 Catalysis and Surface Science of Materials
ME 2820 Materials Processing
ME 3801 Experimental Methods in Material Science and Engineering
ME 4814 Biomaterials
ME 4821 Chemistry, Properties, and Processing of Plastics
ME 4840 Physical Metallurgy
ME 48xx (Materials courses as approved)

PROJECT OPPORTUNITIES

Projects available to the chemical engineering student are of the widest possible variety. Projects may be of the research type (as would be encountered in graduate school) or of a more developmental, industrial nature. Nonexperimental design projects or theoretical projects are also available. They are available on campus, sometimes with graduate students working on sponsored research; in off-campus governmental laboratories; or in industry, as well as overseas.

Areas of specialization in the department currently are:
Adsorption   Kinetics
Biochemical Engineering Mass Transfer
Biofilms Materials Synthesis
Biominiaturization Microfluidics
Bioremediation Molecular Modeling
Biosensors Process Dynamics
Biototechnology Supervision and Control
Catalysis Reaction Engineering
Diffusion Scientific Computing
Drug Delivery Separation Processes
Fuel Cells Thermodynamics
Bioremediation Water Remediation
Biosensors Zeolites

CHEMICAL ENGINEERING SUGGESTED COURSE SEQUENCE

- MAIN SEQUENCE
- ELECTIVES
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.

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics and Physics (Note 1).</td>
<td>2</td>
</tr>
<tr>
<td>2. Chemistry and Biochemistry (Note 2).</td>
<td>4</td>
</tr>
<tr>
<td>3. Biology (Note 3).</td>
<td>1 2/3</td>
</tr>
<tr>
<td>4. Chemistry and Biochemistry/Biology Laboratory (Note 4).</td>
<td>1</td>
</tr>
<tr>
<td>5. Other Natural or Computer Science (Note 5).</td>
<td>1/3</td>
</tr>
<tr>
<td>6. MQP</td>
<td>1</td>
</tr>
</tbody>
</table>

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 four units must include one unit of organic, one unit of biochemistry, and 1/3 unit each of physical (3000 level or higher) and inorganic chemistry (3000 level or higher).
3. These 1 2/3 units must include 1/3 unit of cell biology, 1/3 unit of genetics, and 2/3 unit of advanced work (3000 level or higher).
4. This unit must include a minimum of 1/3 unit in Chemistry and Biochemistry, and a minimum of 1/3 unit in Biology.
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

<table>
<thead>
<tr>
<th>Year</th>
<th>Term A</th>
<th>Term B</th>
<th>Term C</th>
<th>Term D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CH 1010</td>
<td>CH 1020</td>
<td>CH 1030</td>
<td>CH 1040</td>
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<td></td>
<td>BB 2350</td>
<td>MA</td>
<td>BB 2920</td>
<td>HU</td>
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<td>MA</td>
<td>MA</td>
<td>MA</td>
</tr>
<tr>
<td></td>
<td>CH 3510</td>
<td>CH 2310</td>
<td>CH 2320</td>
<td>CH 2330</td>
</tr>
<tr>
<td></td>
<td>CH 2640</td>
<td>SS</td>
<td>HU</td>
<td>HU</td>
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<td></td>
<td>HU</td>
<td>SU</td>
<td>PH</td>
<td>PH</td>
</tr>
<tr>
<td></td>
<td>CH 4110</td>
<td>CH 4120</td>
<td>CH 4130</td>
<td>CH 4170</td>
</tr>
<tr>
<td></td>
<td>BB Lab</td>
<td>CH 4150</td>
<td>CH 3410</td>
<td>Elective IQP</td>
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<td></td>
<td>SS</td>
<td>IQP</td>
<td>IQP</td>
<td>IQP</td>
</tr>
<tr>
<td></td>
<td>Elective MQP</td>
<td>Elective MQP</td>
<td>CH 4160</td>
<td>CH 4190</td>
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<td></td>
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<td>Elective</td>
<td>MQP</td>
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<td></td>
<td>Elective</td>
<td>Elective</td>
<td>Elective</td>
<td>Elective</td>
</tr>
</tbody>
</table>
ASSOCIATED BIOCHEMISTRY FACULTY
D. S. Adams (BB), M. Buckholt (BB), J. Duffy (BB),
S. M. Politz (BB), R. Prusty-Rao (BB), J. Rulfs (BB),
E. Ryder (BB), P. J. Weathers (BB)

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

1. Mathematics and Physics (Note 1). 2 1/3
2. Chemistry (Note 2). 4
3. Additional Science/Engineering (Note 3). 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. 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

<table>
<thead>
<tr>
<th>Year</th>
<th>Term A</th>
<th>Term B</th>
<th>Term C</th>
<th>Term D</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>CH 1010</td>
<td>CH 1020</td>
<td>CH 1030</td>
<td>CH 1040</td>
</tr>
<tr>
<td>Second</td>
<td>CH 2640 (lab)</td>
<td>CH 2650 (lab)</td>
<td>CH 2660 (lab)</td>
<td>CH 2670 (lab)</td>
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<tr>
<td></td>
<td>CH 3510 (phys)</td>
<td>CH 2310 (org)</td>
<td>CH 2320 (org)</td>
<td>CH 2330 (org)</td>
</tr>
<tr>
<td>Third</td>
<td>CH 3550 (phys)</td>
<td></td>
<td>CH 3410 (org)</td>
<td>CH 3530 (phys)</td>
</tr>
<tr>
<td>Fourth</td>
<td>CH 4110 (bioch)</td>
<td></td>
<td></td>
<td>CH 4420 (org)</td>
</tr>
</tbody>
</table>

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 Biochemistry I
- CH 4120 Biochemistry II
- CH 4130 Biochemistry III
- BB 4910 Advanced Molecular Biology
- BB 4955 Recombinant DNA Principles and Applications
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 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
- Ion Transport
- Materials
- Medicinal Chemistry
- Membrane Proteins
- Molecular Spectroscopy
- Nanoscale Design
- Natural Products Synthesis
- Plant-Virus Biochemistry
- Photochemistry
- Photophysics
- Sensors
- Supramolecular Chemistry

**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)

<table>
<thead>
<tr>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 level CH course</td>
</tr>
<tr>
<td>2000 level CH courses (Note 2)</td>
</tr>
<tr>
<td>3000/4000 level CH courses</td>
</tr>
<tr>
<td>4000 level CH courses (capstone)</td>
</tr>
</tbody>
</table>

**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 1020 Forces and Bonding
- CH 2310 Organic Chemistry I
- CH 3510 Chemical Thermodynamics
- CH 3510 Chemical Thermodynamics
- CH 3410 Principles of Inorganic Chemistry
- CH 4110 Biochemistry I

**CH Minor with Depth in Physical Chemistry**

- CH 1020 Forces and Bonding
- CH 2320 Organic Chemistry II
- CH 3510 Chemical Thermodynamics
- CH 3510 Chemical Thermodynamics
- CH 3410 Principles of Inorganic Chemistry
- CH 4520 Chemical Statistical Mechanics

Many other sequences are possible.
CIVIL AND ENVIRONMENTAL ENGINEERING

T. EL-KORCHI, HEAD
PROFESSORS: T. El-Korchi, F. L. Hart, J. C. O'Shaughnessy, M. Ray
ASSISTANT PROFESSOR: M. Too
ADJUNCT FACULTY: J. Hall, L. Malloy
EMERITUS PROFESSORS: F. DeFalco, R. Fitzgerald

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.

PROGRAM OUTCOMES
1. Preparation for engineering practice, including the technical, professional, and ethical components.
2. Preparation for the future changes in civil engineering.
3. A solid understanding of the basic principles of civil engineering.
4. An understanding of appropriate scientific concepts, and an ability to apply them to civil engineering.
5. An understanding of the engineering design process and an ability to perform engineering design, which includes the multidisciplinary aspects of the engineering design process, the need for collaboration and communications skills, plus the importance of cost and time management.
6. Demonstration of an ability to set up experiments, gather and analyze data, and apply the data to practical engineering problems.
7. Demonstration of in-depth understanding of at least one subarea within civil engineering.
8. Understanding of options for careers and further education, and the educational preparation necessary to pursue those options.
9. An ability to learn independently.
10. The broad education envisioned by the WPI Plan, and described by the Goal and Mission of WPI.
11. An understanding of civil engineering profession in a societal and global context.

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. Areas 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 4046, 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.

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 50 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-Korch, P. Jayachandran, R. Mallick, M. Ray, M. Tao)

The practice of structural engineering involves the analysis and design of buildings, bridges 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, F. Hart, P. Mathisen, J. O’Shaughnessy, J. Plummer)

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.

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**CIVIL ENGINEERING PROGRAM CHART**

This chart summarizes course and scheduling recommendations. Students should refer to the Program Distribution Requirements for detailed information.

<table>
<thead>
<tr>
<th>First Year/ Sophomore</th>
<th><strong>MATHEMATICS AND SCIENCE (4 units minimum required)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Math MA 1020 or MA 1021, MA 1022, MA 1023, MA 2051, MA 2611</td>
</tr>
<tr>
<td></td>
<td>Science CH 1010, CH 1020, PH 1110, GE 2341, BB 1001</td>
</tr>
<tr>
<td></td>
<td>Other Math and Science MA 1024, MA 2071, MA 2210, PH 1120, BB 1002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Junior</th>
<th><strong>HUMANITIES AND ARTS (2 units minimum required)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SOCIALLY SCIENCE (2/3 units minimum required)</td>
</tr>
<tr>
<td></td>
<td>IQP (1 unit minimum required)</td>
</tr>
<tr>
<td>Anytime</td>
<td><strong>PHYSICAL EDUCATION (1/3 unit minimum required)</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First Year/ Sophomore</th>
<th><strong>ENGINEERING SCIENCE AND DESIGN (6 units minimum required; 4 units minimum required in Civil Engineering)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Junior/ Senior</td>
<td>Computer Applications CE 3030, CE 3031</td>
</tr>
<tr>
<td></td>
<td>Outside of CE ES 2001, ES 3001, ECE 3601 or other 2000-level or above engineering course</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Civil Engineering Subareas</th>
<th>Structural</th>
<th>Geotechnical</th>
<th>Environmental and Hydraulics</th>
<th>Urban and Environmental Planning</th>
<th>Transportation</th>
<th>Construction Engineering and Project Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Courses</td>
<td>CE 3010</td>
<td>CE 3041</td>
<td>CE 3059</td>
<td>CE 3070</td>
<td>CE 3050</td>
<td>CE 3020</td>
</tr>
<tr>
<td></td>
<td>CE 3006</td>
<td>CE 3044</td>
<td>CE 3060</td>
<td>CE 3074</td>
<td>CE 3051</td>
<td>CE 3021</td>
</tr>
<tr>
<td></td>
<td>CE 3008</td>
<td></td>
<td>CE 3061</td>
<td>CE 4071</td>
<td></td>
<td>CE 3022</td>
</tr>
<tr>
<td></td>
<td>CE 4007</td>
<td></td>
<td>CE 3062</td>
<td></td>
<td></td>
<td>CE 3023</td>
</tr>
<tr>
<td></td>
<td>CE 4017</td>
<td></td>
<td>CE 4061</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CE 4017</td>
<td></td>
<td>CE 4600</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labs</td>
<td>CE 3026</td>
<td>CE 4046</td>
<td>CE 4060</td>
<td>CE 4054</td>
<td>CE 3024</td>
<td></td>
</tr>
<tr>
<td>MQP</td>
<td>Project in areas of interest, including capstone design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anytime</td>
<td><strong>ELECTIVES (1 unit)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TRANSPORTATION ENGINEERING
(T. El-Korch, R. Mallick, M. Ray, 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
(P. Mathisen, J. Plummer)
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, R. Pietroforte, 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 the analysis and design of innovative water and wastewater treatment systems, water quality monitoring and pollutant control, water resources analysis and groundwater studies.

<table>
<thead>
<tr>
<th>Course No.</th>
<th>Course Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE 3059</td>
<td>Environmental Engineering</td>
</tr>
<tr>
<td>CE 3060</td>
<td>Water Treatment</td>
</tr>
<tr>
<td>CE 3061</td>
<td>Wastewater Treatment</td>
</tr>
<tr>
<td>CE 3062</td>
<td>Hydraulics</td>
</tr>
<tr>
<td>CE 3070</td>
<td>Urban and Environmental Planning</td>
</tr>
<tr>
<td>CE 3074</td>
<td>Environmental Analysis</td>
</tr>
<tr>
<td>CE 4060</td>
<td>Environmental Engineering Laboratory</td>
</tr>
<tr>
<td>CE 4061</td>
<td>Hydrology</td>
</tr>
<tr>
<td>CE 4071</td>
<td>Land Use Development &amp; Controls</td>
</tr>
<tr>
<td>CE 4600</td>
<td>Hazardous and Industrial Waste Management</td>
</tr>
<tr>
<td>CHE 3201</td>
<td>Kinetics and Reactor Design</td>
</tr>
<tr>
<td>CHE 3920</td>
<td>Air Quality Management</td>
</tr>
</tbody>
</table>

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 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 in October and April each year.
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 four courses for both the Bachelor's and Master's degree requirements. 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

M.A. GENNERT, HEAD
D. FINCKEL, ASSOCIATE HEAD


ASSOCIATE PROFESSORS: E. Agu, K. Fisler, M.A. Gennert, N. Heffernan, G.T. Heineman, C. Ruiz, C.E. Wills


PROFESSOR OF PRACTICE: G.F. Pollice

AFFILIATED ASSOCIATE PROFESSOR: G.N. Sarkozy

ADJUNCT ASSISTANT PROFESSOR: H.C. Lauer

INSTRUCTOR: G. Hamel

PROFESSORS EMERITUS: M.H. Hardell, K.A. Lemone

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) mathematics, basic science, and related fields as follows

<table>
<thead>
<tr>
<th>COMPUTER SCIENCE</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Computer Science (including the MQP) (Notes 1, 2).</td>
<td>6</td>
</tr>
<tr>
<td>2. Mathematics (Notes 2, 3, 5).</td>
<td>7/3</td>
</tr>
<tr>
<td>3. Basic Science and/or Engineering Science (Notes 2, 4).</td>
<td>5/3</td>
</tr>
</tbody>
</table>

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 2118 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 (CS 3043, STS 2208, GOV/ID 2314). (If STS 2208 or GOV/ID 2314 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 courses. These units can also be met by WPI graduate CS courses.
d. 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.
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, RBE disciplines. At least three courses must come from BB, CH, GE, 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.

The Computer Science Department offers a second program, Computers with Applications, which is not accredited by the Computing Accreditation Commission of ABET. The distribution requirements for that program are:

**Program Distribution Requirements for the Computers with Applications Major**

<table>
<thead>
<tr>
<th>COMPUTERS WITH APPLICATIONS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Computer Science (including the MQP) (Notes 1, 2).</td>
<td>16/3</td>
</tr>
<tr>
<td>2. Mathematics (Note 2).</td>
<td>7/3</td>
</tr>
<tr>
<td>3. Basic Science (Notes 2, 3).</td>
<td>2/3</td>
</tr>
<tr>
<td>4. Application Area (Notes 2, 4).</td>
<td>5/3</td>
</tr>
</tbody>
</table>

**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 2118 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 (CS 3043, STS 2208, GOV/ID 2314). (If STS 2208 or GOV/ID 2314 is used to satisfy this requirement, it does not count as part of the 16/3 units of CS.)

### COMPUTER SCIENCE PROGRAM CHART

**COMPUTER SCIENCE**
Minimum 18/3

**CORE COURSES**
Minimum 1/3
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

**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, STS 2208, GOV/ID 2314
STS 2208, GOV/ID 2314 do not count toward the 18/3 CS units

**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, RBE courses. At least three courses must come from BB, CH, GE, 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
c. At least 5/3 units of the Computer Science requirement must consist of 4000-level courses. These units can also be met by WPI graduate CS courses, with the exception of CS 501 and CS 507.

d. The MQP must involve the application of computer science concepts to the Application Area specified in Requirement 4.

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.

2. A cross-listed course may be counted toward only one of areas 1, 2, 3, 4 above.

3. The two courses satisfying the science requirement must both come from one of the following disciplines: BB, CH, GE, PH.

4. This requirement is satisfied by a cohesive set of work from disciplines other than Computer Science. Work used for any other degree requirements cannot be used for the Application Area. At least 3/3 units must be course work at the 3000 level or higher. Independent Study/Project (ISP) work, if any, must be conducted under the supervision of a member of the faculty in that discipline.

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 the Budapest Project Center, the Lincoln Laboratory Project Center, the Silicon Valley Project Center, and the Wall Street Project Center.

Projects are also available on campus, both to support the ongoing 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 including assistance with, and development of, computer science education at neighboring area schools.

COMPUTER SCIENCE MINOR

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 conclude with one of the following, each of which provides an integrating capstone experience:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 3013</td>
<td>Operating Systems</td>
</tr>
<tr>
<td>CS 3041</td>
<td>Human-Computer Interaction</td>
</tr>
<tr>
<td>CS 3133</td>
<td>Foundations of Computer Science</td>
</tr>
<tr>
<td>CS 3431</td>
<td>Database Systems I</td>
</tr>
<tr>
<td>CS 3516</td>
<td>Computer Networks</td>
</tr>
<tr>
<td>CS 3733</td>
<td>Software Engineering</td>
</tr>
<tr>
<td>CS 4120</td>
<td>Analysis of Algorithms</td>
</tr>
<tr>
<td>CS 4123</td>
<td>Theory of Computation</td>
</tr>
<tr>
<td>CS 4235</td>
<td>Object-Oriented Analysis and Design</td>
</tr>
<tr>
<td>CS 4241</td>
<td>Webware: Computational Technology for Network Information Systems</td>
</tr>
<tr>
<td>CS 4341</td>
<td>Introduction to Artificial Intelligence</td>
</tr>
<tr>
<td>CS 4432</td>
<td>Database Systems II</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 4445</td>
<td>Data Mining</td>
</tr>
<tr>
<td>CS 4513</td>
<td>Distributed Computing Systems</td>
</tr>
<tr>
<td>CS 4515</td>
<td>Computer Architecture</td>
</tr>
<tr>
<td>CS 4516</td>
<td>Advanced Computer Networks</td>
</tr>
<tr>
<td>CS 4533</td>
<td>Techniques of Programming Language Translation</td>
</tr>
<tr>
<td>CS 4536</td>
<td>Programming Languages</td>
</tr>
<tr>
<td>CS 4731</td>
<td>Computer Graphics</td>
</tr>
<tr>
<td>CS 4732</td>
<td>Computer Animation</td>
</tr>
</tbody>
</table>

- any graduate-level computer science course, except for CS 505 and CS 552.
- 1/3 unit of another activity, for example an ISP, which is validated by a CS faculty member as a capstone.

Students interested in initiating work on a minor in CS are encouraged to ask the Computer Science Department to identify a faculty member to assist the student in structuring a minor. Prior to the initiation of a capstone experience students must inform the offering professor of their intent to use the experience as a capstone.

Majors in Computer Science and Computers with Applications do not qualify for a Minor in Computer Science.

ECE majors and Management Information Science majors 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 10.

F. J. LOOF, HEAD; H. HAKIM, ASSOCIATE HEAD


ASSISTANT PROFESSORS: X. Huang, A. Klein, W. Lou, T. Padir, A. Wyglinksi

PROFESSOR OF PRACTICE: R. Labonte

AFFILIATE PROFESSOR: R. H. Campbell

INSTRUCTORS: S. J. Btar, G. Bogdanov, S. M. Jarvis


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 department educates future leaders of the electrical and computer engineering profession, with a program characterized by curricular flexibility, student project work, and active involvement of students in their learning. Through a balanced, integrated curriculum we provide an education which is strong both in the fundamentals and in state-of-the-art knowledge, appropriate for immediate professional practice as well as graduate study and lifelong learning. Such an education also prepares students broadly for their professional and personal lives, providing the basis for effective leadership and informed citizenship. The curriculum embraces WPI’s philosophy of education, and takes advantage of key components such as the Interactive Qualifying Project to develop technical professionals who possess the ability to communicate, work in teams, and understand the broad implications of their work.

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

1. Preparation for engineering practice, including the technical, professional, and ethical components
2. Preparation for future changes in electrical and computer engineering
3. A solid understanding of the basic principles of electrical engineering, computer engineering, and the relationship between hardware and software
4. An understanding of appropriate mathematical concepts, and an ability to apply them to ECE
5. An understanding of the engineering design process, and ability to perform engineering design, including the needed teamwork and communications skills.
6. Demonstration of in-depth understanding of at least one specialty within ECE
7. An ability to communicate effectively in written and oral form
8. An understanding of options for careers and further education, and the necessary educational preparation to pursue those options
9. An ability to learn independently
10. The broad education envisioned by the WPI Plan, and described by the Goal and Mission of WPI
11. An understanding of engineering and technology in a societal and global context.

**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 major 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**
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, discrete mathematics, and probability and/or statistics.
   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 (except ECE 3601) 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, 2201, 2204, 2305, 2312, 3011, 3113, 3204, 3308, 3511, 3501, 3503, 4011, 4305, 4703, 4902, 4904, and ES 3011.
   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 2801, 3801, 3803, 3810 and 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 at least 1/3 unit of engineering science (prefix ES) at the 2000 level or above. ES 3011 cannot be applied to this requirement.
   g. Must include an additional 1/3 unit of engineering science and design at the 2000 level or above, selected from courses having the prefix BME, CE, CHE, CS (other than CS 2011, CS 2022, CS 3043), ECE (other than ECE 3601), ES, FP, ME, or RE.

**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: Cyganski, Duckworth, Looft, Michalson  

**Area Courses**  
ECE 2022 Introduction to Digital Circuits and Computers  
ECE 2801 Foundations of Embedded Computer Systems  
ES 3011 Control Engineering I  
ECE 3803 Microprocessor System Design  

**Related Courses**  
ECE 2201 Microelectronics I  
ECE 3503 Power Electronics  
CS 4341 Artificial Intelligence  
RBE 1001 Introduction to Robotics  
RBE 2001 Unified Robotics I  
RBE 2002 Unified Robotics II  
RBE 3001 Unified Robotics III  
RBE 3002 Unified Robotics IV  

**Power Systems Engineering**  
Area Consultants: Emanuel, Hakim  

**Area Courses**  
ECE 3501 Electrical Energy Conversion  
ECE 3503 Power Electronics  

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

**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, Cyganski, Hakim, Klein, Makarov, Pahlavan, Pedersen, 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, Pedersen  

**Area Courses**  
ECE/BME 2204 Bioelectric Foundations  
ECE/BME 3011 Bioinstrumentation and Biosensors  
ECE/BME 4011 Biomedical Signal Analysis  

**Related Courses**  
ECE 2201 Microelectronic Circuits I  
ECE 2312 Discrete-Time Signal and System Analysis  
ECE 3204 Microelectronic Circuits II  
BME 4023 Biomedical Instrumentation Design  
BME 4201 Biomedical Imagery  

**Analog Microelectronics**  
Area Consultants: Bitar, Labonte, McNeill  

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

**Related Courses**  
ES 3011 Control Engineering I  
ECE 3801 Advanced Logic Design  

**Computer Engineering**  
Area Consultants: Clancy, Cyganski, Duckworth, Hakim, Huang, Jarvis, Looft, Lou, Michalson  

**Area Courses**  
ECE 2801 Foundations of Embedded Computer Systems  
ECE 3801 Advanced Logic Design  
ECE 3803 Microprocessor System Design  
ECE 3810 Advanced Digital System Design  
ECE 4801 Advanced Computer System 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 one Engineering Science course. Both 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.) In the Computer Science area, most students will need to complete a CS course at the 1000-level before attempting requirements at the 2000-level or above. Many students find it advantageous to take more than the minimum CS course requirement. CS 2301 is highly recommended for ECE students.

The Engineering Science courses represent cross-disciplinary areas that are applicable to many engineering and science departments.

#### 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, discrete mathematics, and probability and/or statistics. 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 complete a minimum of two units of work while meeting the following requirements:

1. Required course: Either ECE 2011 or ECE 3601
2. At least three courses from the following list:
   - ECE 2022, ECE 2111, ECE 2112, ECE 2201, ECE 2311, ECE 2312, ECE 2801, either CS 2301 or CS 2303, or any ECE course at 3000 or 4000 level with the exception of 3601.
3. At least two ECE courses at the 3000-level or above which are thematically related. The thematically related courses can be areas of concentration such as Analog and RF Electronics, Control and Power Engineering, Computer Engineering, or Communications and Signals. Examples of thematically related 3000 and 4000 level courses are:
   - a. ECE 3311, ECE 4305, ECE 4703 (Communications and Signals)
   - b. ECE 3801, ECE 3803, ECE 4801 (Computer Engineering)
   - c. ECE 3204, ECE 3113, ECE 4902 (Analog and RF Electronics)
   - d. ES 3011, EC E3501, ECE 3503 (Control and Power Engineering)

4. A capstone experience through an ISP or an ECE course at 3000-level or above. The ISP can replace one of the courses required under item 3 with the exception of 3601.

The above thematically arranged courses represent four examples of important ECE sub-disciplines; additional areas of concentration, for example in Robotics or Biomedical Engineering, can be made in consultation with relevant ECE faculty members. Students seeking an ECE Minor should complete the ECE Minor form available in the ECE office 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.

ENGINEERING PHYSICS

ADVISOR: G. S. Iannacchione

Programs of study in Engineering Physics are listed under the Physics Department. These programs include specialization in such areas as computational techniques, optics, electromagnetism, materials science and engineering, nuclear science and engineering, and thermal physics.
ENVIRONMENTAL ENGINEERING

DIRECTOR: J. PLUMMER (CEE)
ASSOCIATED FACULTY: J. Bergendahl (CEE), T. Camesano (CHE), W. Clark (CHE), D. DiBiasio (CHE), F. Hart (CEE), N. Kazantzis (CHE), P. Mathisen (CEE), J. O’Shaughnessy (CEE), B. Savlounis (ME), J. Sullivan (ME), R. Thompson (CHE)

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 educational objectives for the Bachelor degree in Environmental Engineering are that all graduates:

1. Are able to apply fundamental principles of mathematics, science, and engineering to solve water, air, and land environmental problems.
2. Have the interpersonal and communication skills, an understanding of ethical responsibility, and a professional attitude necessary for a successful engineering career.
3. Have the ability to engage in lifelong learning.
4. Have an appreciation for the interrelationships between basic scientific knowledge, technology, and societal issues.

PROGRAM OUTCOMES
The educational outcomes for the Bachelor degree in Environmental Engineering are that all graduates will:

1. Be prepared for engineering practice, including technical, professional, and ethical components.
2. Be prepared for future changes in environmental engineering.
3. Have a solid understanding of the basic principles of environmental engineering.
4. Demonstrate knowledge in the areas of water, land, and air systems, and environmental health.
5. Understand appropriate scientific concepts, and have an ability to apply them to environmental engineering.
6. Understand the engineering design process and have an ability to perform engineering design, which includes the multidisciplinary aspects of the engineering design process, the need for collaboration and communication skills, plus the importance of cost and time management.
7. Have the ability to collect, analyze and interpret experimental data.
8. Understand options for careers and further education, and the educational preparation necessary to pursue those options.
9. Have an ability to learn independently.
10. Have the broad education envisioned by the WPI Plan, and described by the Goal and Mission of WPI.
11. Have an understanding of the environmental engineering profession in a societal and global context.

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

<table>
<thead>
<tr>
<th>Mathematics and Basic Science (4 Units Required)</th>
<th>5/3 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Differential and integral calculus; differential equations</td>
<td>1/3 unit</td>
</tr>
<tr>
<td>Statistics (MA 2611 recommended)</td>
<td>1/3 unit</td>
</tr>
<tr>
<td>Biology (BB)</td>
<td>3/3 units</td>
</tr>
<tr>
<td>Chemistry (CH)</td>
<td>1/3 unit</td>
</tr>
<tr>
<td>Earth science (GE 2341 recommended)</td>
<td>1/3 unit</td>
</tr>
<tr>
<td>Physics (PH, calculus-based)</td>
<td>1/3 unit</td>
</tr>
</tbody>
</table>

**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.

### Engineering Science

<table>
<thead>
<tr>
<th>Thermofluids</th>
<th>minimum 2/3 units</th>
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</thead>
<tbody>
<tr>
<td>ES 3001 Introduction to Thermodynamics (or CHE 2013 or CH 3510)</td>
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<td>ES 3002 Mass Transfer</td>
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<tr>
<td>ES 3004 Fluid Mechanics</td>
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<td>CHE 3501 Applied Mathematics in Chemical Engineering</td>
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<tr>
<th>Mechanics and Materials</th>
<th>minimum 2/3 units</th>
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<tbody>
<tr>
<td>CE 2000 Analytical Mechanics I (or ES 2501)</td>
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<tr>
<td>CE 2001 Analytical Mechanics II (or ES 2502)</td>
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<tr>
<td>ES 2001 Introduction to Material Science</td>
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<tr>
<td>ES 2503 Introduction to Dynamic Systems</td>
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</table>

### Core Environmental Engineering

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

### Environmental Engineering Electives

<table>
<thead>
<tr>
<th>Water Quality and Resources</th>
<th>minimum 3/3 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE 3060 Water Treatment</td>
<td></td>
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<tr>
<td>CE 3061 Wastewater Treatment</td>
<td></td>
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<tr>
<td>CE 4060 Environmental Engineering Laboratory</td>
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<tr>
<td>CE 4061 Hydrology</td>
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<table>
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<tr>
<th>Air and Land Environmental Systems</th>
<th>minimum 2/3 units</th>
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<tbody>
<tr>
<td>CE 3041 Soil Mechanics</td>
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<tr>
<td>CE 3074 Environmental Analysis</td>
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<tr>
<td>CE 4600 Hazardous and Industrial Waste Management</td>
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<tr>
<td>CHE 3920 Air Quality Management</td>
<td></td>
</tr>
<tr>
<td>CHE 4401 Unit Operations of Chemical Engineering I</td>
<td></td>
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</tbody>
</table>

### Environmental Management

<table>
<thead>
<tr>
<th>minimum 1/3 unit</th>
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<tbody>
<tr>
<td>CE 3020 Project Management</td>
</tr>
<tr>
<td>CE 3070 Urban and Environmental Planning</td>
</tr>
<tr>
<td>CE 4071 Land Use Development and Controls</td>
</tr>
</tbody>
</table>

### Major Qualifying Project

3/3 units

**ADDITIONAL DEGREE REQUIREMENTS (4 units Required)**

<table>
<thead>
<tr>
<th>Humanities and Arts</th>
<th>6/3 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social Science‡</td>
<td>2/3 units</td>
</tr>
<tr>
<td>IQP</td>
<td>3/3 units</td>
</tr>
<tr>
<td>Physical Education</td>
<td>1/3 unit</td>
</tr>
</tbody>
</table>

‡ Many SS courses compliment topics in environmental engineering. Courses in policy, regulations, law and environmental problems are recommended.
EDUCATIONAL OUTCOMES
Graduating Students will:
1. Be able to identify, analyze, and develop solutions to environmental problems creatively through sustained, multifaceted investigation.
2. Have mastered fundamental concepts and methods of inquiry in their areas of specialization, whether environmental thought, policy, or methodology.
3. Be able to make connections between environmental 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.

Distribution Requirements

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Environmental Studies Core (Note 1)</td>
<td>1</td>
</tr>
<tr>
<td>2. Mathematics &amp; Basic Science (Note 2)</td>
<td>2 2/3</td>
</tr>
<tr>
<td>3. Environmental Science and Engineering (Note 3)</td>
<td>3</td>
</tr>
<tr>
<td>4. Basic Social Science and Humanities (Note 4)</td>
<td>1</td>
</tr>
<tr>
<td>5. Environmental Social Science and Humanities (Note 5)</td>
<td>2</td>
</tr>
<tr>
<td>6. MQP</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>10 2/3</strong></td>
</tr>
</tbody>
</table>

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 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 Studies students do an environmentally-related IQP. However, for interested students, numerous opportunities exist for environmental IQPs on campus and at off-campus centers. In a typical academic year, approximately 30 of the 80 IQPs completed at off-campus project centers are environmental in nature. 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.
FIRE PROTECTION ENGINEERING

K. A. NOTARIANII, HEAD
ASSOCIATE PROFESSORS: L. Albano, N. A. Dembsey, B. Meacham, K. A. Notарианні
ASSISTANT PROFESSOR: A. Rangwala
PROFESSOR OF PRACTICE: M. Puchovsky
FPE EMERITUS: R. W. Fitzgerald, D. A. Lucht, R. E. Zalosh

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. BOUDREAU, HEAD
ASSOCIATE PROFESSORS: W. A. Addison, Jr., M. Ephraim, P. H. Hansen, A. A. Rivera, J. Rudolph, M. D. Samson, J. Sanbonmatsu, R. L. Smith

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

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Humanities and Arts (including MQP) (Note 1)</td>
<td>6</td>
</tr>
<tr>
<td>2. Mathematics and Science (Note 2)</td>
<td>2</td>
</tr>
<tr>
<td>3. Electives (Note 3)</td>
<td>2</td>
</tr>
</tbody>
</table>

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

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, EN, or RH (2000 level or higher) and MQP in Drama/Theatre

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

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

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.

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 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 American Foreign Policy from Woodrow Wilson to the Present
HI 2317 Law and Society in America, 1865-1910
HI 3311 American Labor History
HI 3312 Topics in American Social History
HI 3314 The American Revolution
HI 3333 Topics in American Technological Development
**List 2. American Literature:**
- EN 2221 American Drama
- EN 2231 American Literature: The Raven, the Whale, and the Woodchuck
- EN 2232 American Literature: Twain to the Twentieth Century
- EN 2233 American Literature: Twentieth Century
- EN 2234 Modern American Novel
- EN 2235 The American Dream: Myth in Literature and the Popular Imagination
- EN 2237 American Literature and the Environment
- EN 2238 American Realism
- EN 3221 New England Supernaturalism
- EN 3232 The Concord Writers
- EN 3233 Worcester Between the Covers: Local Writers and Their Works
- EN 3224 Modern American Poetry
- EN 3237 Pursuing Moby-Dick

**List 3. American Politics, Law, and Policy:**
- GOV 1301 U.S. Government
- GOV 1303 American Public Policy
- GOV 1310 Law, Courts, and Politics
- STS 1207 Introduction to the Psycho-sociology of Science
- GOV 2302 Science-Tech Policy
- STS 2208 The Society-Tech Debate
- GOV 2304 Governmental Decision Making and Administrative Law
- GOV 2310 Constitutional Law

**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 2113 Topics in 19th- and 20th-Century Architecture
- EN 2237 American Literature and the Environment
- HI 1311 Introduction to American Urban History
- HI 1341 Introduction to Global History
- HI 2353 History of the Life Sciences
- HI 2401 U.S. Environmental History
- HI 3331 Topics in the History of European Science and Technology
- HI 3333 American Technological Development
- HI 3335 Topics in the History of Non-Western Science and Technology
- PY 2712 Social and Political Philosophy
- PY 2713 Bioethics
- PY 2717 Philosophy and the Environment

**List 2. Related Environmental Courses in Social Sciences:**
- ECON 2117 Environmental Economics
- ECON 2125 Development Economics
- GOV 2312 International Environmental Policy
- ENV 2400 Environmental Problems and Human Behavior

**List 3. Environmental Courses in Other Areas:**
- BB 2040 Principles of Ecology
- CHE 3910 Chemical and Environmental Technology
- CHE 3920 Air Quality Management
- CE 3059 Environmental Engineering
- CE 3070 Urban and Environmental Planning
- CE 3074 Environmental Analysis
- ME 3422 Environmental Issues and Analysis

**HUMANITIES AND ARTS WITH HUMANITIES STUDIES OF SCIENCE AND TECHNOLOGY CONCENTRATION**

This interdisciplinary concentration enables students to apply to 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**
- AR 2113 Topics in 19th- and 20th-Century Architecture
- EN 2252 Science and Scientists in Modern Literature
- EN 3215 Genres of Science Writing
- HI 1311 Introduction to the History of Science
- HI 1324 Introduction to the History of Technology
- HI 2313 Science, Technology, and Culture in the Early American Republic
- HI 2332 History of Modern American Science and Technology
- HI 2352 History of the Exact Sciences
- HI 2353 History of the Life Sciences
- HI 2354 History of the Physical Sciences
- HI 2401 U.S. Environmental History
- HI 2402 History of Evolutionary Thought
- 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
- PY 2713 Bioethics
- PY 2717 Philosophy and the Environment

**List 2: Closely Related Courses in Humanities**
- AR 3112 Modernism, Mass Culture, and the Avant-Garde
- HI 1311 Introduction to American Urban History
- HI 2324 Industry and Empire in British History
- HI 3311 American Labor History
- HI 3323 Topics in the Western Intellectual Tradition
- PY 2711 Philosophical Theories of Knowledge and Reality

**List 3: Science-Technology-Studies Courses in Other Areas**
- AR/ID 3150 Light, Vision and Understanding and the Scientific Community
- STS 1207 Introduction to the Psycho-Sociology of Science
- STS 2208 The Science-Tech Debate
- GOV 2302 Science-Tech Policy
- GOV 2304 Governmental Decision Making and Administrative Law
- GOV 2312 International Environmental Policy
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.

HUMANITIES AND ARTS MINORS

Minors can be arranged in areas other than the above. See Prof. Addison, 39 Dean Street, for further information about minors in other areas and interdisciplinary minors.

DRAMA/THEATRE MINOR

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 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: 1 1/3 units chosen from among the following:
   - EN 1221, EN 1222, EN 2221, EN 2222, EN 2224, EN 3222, EN 3223, EN 3224, or any IS/P designated TH.
2. Drama/Theatre Performances: 1/3 unit (at least two 1/6 unit TH IS/P, Independent Study/Projects).
3. Drama/Theatre Capstone Experience: 1/3 unit, Independent Study/Project (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 or Sufficiency Requirement may be applied to the Drama/Theatre minor. The final Inquiry Seminar or Practicum or Sufficiency Project 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.

MINOR IN FOREIGN LANGUAGE (GERMAN OR SPANISH)

The minor in Foreign 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
   - 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 IS/P 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. Dollenmayer (for German) or Prof. Rivera (for Spanish).

MUSIC MINOR

The minor in Music is for students who choose to continue their studies in Music beyond the Humanities and Arts Requirement without majoring 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 major, should consider the Music minor option. Interested students should speak with one of the music faculty in the Department of Humanities and Arts. Because performance is an integral component of music study with proposed minor will contain performance emphasis and consist of two units of work distributed as follows:

1. 1/3 unit for participation in MU IS/P Ensembles.
2. 1/3 unit Performance IS/P as the capstone experience.
   Student, with faculty guidance, will present a recital, original composition, or other musical performance that demonstrates the student's skill and knowledge.
3. 1 1/3 units of music courses.
4. If a student completes his/her Humanities and Arts Requirement in music, 1 unit of that work may be applied to the minor except for the final IS/P.
5. A student who is pursuing a major in Humanities and Arts with music as the major field cannot also receive a minor in music.
WRITING AND RHETORIC MINOR

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 Professor Lorraine Higgins (ldh@wpi.edu) for more information.

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

1. 2/3 unit. Core courses in writing and rhetoric: RH 3111, RH 3112
2. 1 unit. Electives in writing and rhetoric, chosen from the following: EN/WR 2210, EN/WR 2211, EN/WR 2213, EN/WR 3011, EN/WR 3210, RH 3211, EN/WR 3214, EN/WR 3217 and RH 3211. 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 IS/P. 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 coursework 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.

PROGRAM EDUCATIONAL OBJECTIVES

Educational objectives describe the expected accomplishments of graduates during the first few years after graduation.

1. Industrial Engineering Knowledge and Design Skills. Graduates should be able to support operational decision making and design solutions to address the complex and changing industrial engineering problems faced by organizations in an increasingly global environment, using current methods and technologies.

2. Communication Skills. Graduates should be able to communicate effectively, both orally and in writing, using electronic tools and graphical information.

3. Teamwork and Leadership Skills. Graduates should be able to serve as change agents in the organizations that employ them, based on strong interpersonal and teamwork skills, an understanding of professional and ethical responsibility, an awareness of cultural impacts, and a willingness to initiate.

PROGRAM OUTCOMES

Program outcomes describe what students are expected to know and are able to do by the time of graduation, and are linked to the educational objectives described above.

1. Industrial Engineering Knowledge and Design Skills
   (a) an ability to apply knowledge of mathematics, science, and engineering
   (b) an ability to design and conduct experiments, as well as to analyze and interpret data
   (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
   (d) an ability to identify, formulate, and solve engineering problems
   (e) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

2. Communication Skills
   (f) an ability to communicate effectively.

3. Teamwork and Leadership Skills
   (g) an ability to function on multidisciplinary teams
   (h) an understanding of professional and ethical responsibility
   (i) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
   (j) a recognition of the need for, and an ability to engage in life-long learning
   (k) a knowledge of contemporary issues
Program Distribution Requirements for 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

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics and Basic Science (Notes 1, 2)</td>
<td>4</td>
</tr>
<tr>
<td>2. Industrial Engineering Topics (including the MQP) (Notes 3, 4)</td>
<td>6</td>
</tr>
</tbody>
</table>

Notes:
1. Mathematics must include differential and integral calculus, ordinary differential equations, and 2/3 units in probability and statistics.
2. Basic Science must include both chemistry and physics, with a minimum of two courses in either.
3. Must include 1/3 unit of Capstone Design Experience.
4. Industrial Engineering Topics must include courses in the following three topic areas:
   a. 3 units of Industrial Engineering core courses, including 1/3 unit in each of the following 9 areas: financial modeling, deterministic operations research methods, operations process design, materials management, simulation, stochastic methods in operations research, quality control, information systems design, and leadership skills.
   b. 1 unit in Industrial Engineering electives. 3000/4000 level OIE courses, MIS 3720, MIS 4720, and Operations Research courses at the 3000/4000 level in Mathematics qualify. Courses in financial modeling and organizational science do not qualify.
   c. 1 unit in technical electives. Industrial Engineering electives and any other Engineering Science/Design courses qualify.

INDUSTRIAL ENGINEERING PROGRAM CHART

OVERVIEW OF DEGREE REQUIREMENTS FOR THE IE PROGRAM

<table>
<thead>
<tr>
<th></th>
<th>FIRST YEAR</th>
<th>SECOND YEAR</th>
<th>THIRD YEAR</th>
<th>FOURTH YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>HUMANITIES AND ARTS (2 Units)</td>
<td>6 courses including Inquiry Seminar/Practicum</td>
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</tr>
<tr>
<td>SOCIAL SCIENCE (2/3 Units)</td>
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<td>IQP (1 Unit)</td>
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<tr>
<td>MATH/SCIENCE (9 Units)</td>
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<td>IE CORE (3 Units)</td>
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<td>MIS 4720</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>3000/4000 level OR courses in MA</td>
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<tr>
<td>TECHNICAL ELECTIVES (1 Unit)</td>
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<td></td>
<td>Any engineering/science design course</td>
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<tr>
<td>FREE ELECTIVES (1 Unit)</td>
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<td>MQP (1 Unit)</td>
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<tr>
<td>PHYSICAL EDUCATION (1/3 Unit)</td>
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</tbody>
</table>
INTERACTIVE MEDIA AND GAME DEVELOPMENT

DIRECTOR: M. CLAYPOOL (CS)
CO-DIRECTOR: D. O’DONNELL (HUA)

PROGRAM OUTCOMES
The specific outcomes for the WPI IMGD major are that all graduates will:
1. Understand Artistic and Technical areas related to IMGD.
2. Demonstrate an in-depth understanding of either the Artistic or Technical area related to IMGD.
3. Have a base of technical knowledge in Computer Science, Mathematics and Science.
4. Have a base of artistic knowledge in Art, Music and English.
5. Successfully complete a large-scale IMGD project.
6. Successfully complete a group project with both Technical and Artistic IMGD majors.
7. Be able to creatively express and analyze artistic forms relative to IMGD.
8. Communicate effectively orally, in writing, and in visual media.
9. Be aware of social and philosophical issues pertaining to games and related media.

Program Distribution Requirements for the Interactive Media and Game Development Major

<table>
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<td>Computer Science (Note 2)</td>
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<td>Studio Art (Note 4)</td>
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<tr>
<td>Major Qualifying Project</td>
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</table>

In addition to the requirements listed above, students must satisfy one of the two area requirements, Technical (Computer Science) or Artistic (Humanities and Arts):

AREA                                MINIMUM
Computer Science (Note 8)            10/3
Humanities and Arts (Notes 9, 10, 11) 10/3

Students have electives that can be tailored to meet specific degree requirements and interests:

ELECTIVES                                MINIMUM
Total Electives (Note 12)              3/3

NOTES:
1. Choose from: Critical Studies of Interactive Media and Games (IMGD 1000), The Game Development Process (IMGD 1001), Storytelling in Interactive Media and Games (IMGD 1002).
2. CS 2022 and CS 3043 may not be used to satisfy this requirement.
5. Choose from: Computer Techniques in Music (MU 3611), Computers and Synthesizers in Music (MU 3612), or Digital Sound Design (MU 3613).
6. Courses with the prefix EN, WR or RH.
7. Taken from 2 technical offerings (IMGD 3000 and IMGD 4000) or 2 artistic offerings (IMGD 3500 and IMGD 4500).
8. At least 4/3 from: Human-Computer Interaction (CS 3041), Software Engineering (CS 3733, CS 4233), Computer Architecture (CS 4515), Computer Networks (CS 3516, CS 4516), Graphics (CS 4731), Animation (CS 4732), or Artificial Intelligence (CS 4341).
9. At least 1/3 from each of the following areas: Art (AR), Music (MU) and English (EN, WR or RH).
10. At least 5/3 units at the 2000-level or higher.
11. Students completing the Artistic (Humanities and Arts) Area Requirement must complete a Technical Requirement, described below.
12. Electives must be chosen from the following areas: Computer Science, Humanities and Arts, Interactive Media and Game Development, Mathematics, Science, Social Science, Management, or Engineering.

TECHNICAL REQUIREMENT
Each student choosing the Artistic IMGD area will fulfill a Technical Requirement consisting of six courses as follows:
A. Courses required for all IMGD majors:
1. One Mathematics Course
2. One CS course, not including CS 2022 or 3043
3. One Science (BB, CH, GE, PH) course
B. Additional requirements:
4. A second course in Computer Science, not including CS 2022 or 3043
5. Two additional courses from among Mathematical Sciences, Computer Science, Science (BB, CH, GE, PH) and Engineering (BME, CE, CHE, ECE, ES, FPE, ME, RBE), not including CS 3043.

The courses for the Technical Requirement, part A, are satisfied by the IMGD distribution requirements. The courses in part B may not double-count towards other IMGD requirements, including IMGD elective courses.
INTERDISCIPLINARY PROGRAMS

R. F. VAZ, DEAN
K. RISSMILLER, ASSOCIATE DEAN
ASSISTANT PROFESSORS: R. Krueger, S. Jiusto,
ADJUNCT PROFESSOR: S. Vernon-Gerstenfeld
ADJUNCT ASSISTANT PROFESSORS: F. Carrera, D. Golding,
C. Peet

The Provost Office, in conjunction with the Interdisciplinary and Global Studies Division (IGSD), operates those academic functions or programs which require an interdisciplinary administrative structure. In addition, the IGSD also 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 Prof. R. Vaz in the Project Center 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, Prof. Richard Vaz, 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.

The programs below are the established majors administered through IGSD.

PROFESSIONAL WRITING

CO-DIRECTORS: C. DEMETRY (ME) and J. DeWINTER (HUA)
ASSOCIATED FACULTY: M. Elmes (MG), L. Higgins (HUA),
K. Lemone (CS), A. Rivera (HUA), R. Smith (HUA)

The goal of the Professional Writing program is to prepare communication professionals who can bridge the gap between the public and scientists, engineers, physicians, managers, policymakers, and other experts by presenting technical information in useful and accessible ways.

Professional Writing is an interdisciplinary major or double major that combines work in written, oral, and visual 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. If they wish, majors can select courses and projects in one of four areas of concentration:

- Science writing, medical writing, health communication
- Writing in the public interest, writing for nonprofits
- 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 also prepares students for graduate work in fields such as writing and rhetoric, technical communication, journalism, education, law, public health and medicine, and the study of culture.

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 web site: www.wpi.edu/Academics/Majors/PWR.
TEACHER LICENSING

WPI students wishing to receive the Initial License as middle or high school teachers in Massachusetts or states with reciprocating agreements with MA in the areas of Biology, Chemistry, Mathematics or Physics can do so by passing the Massachusetts MTEL test, taking a Teaching Methods course (ID 3100), performing observation and practice teaching and developing an IQP based on this experience, and taking Psychology of Education (PSY 2401) and Cross-Cultural Psychology (PSY 2406). Also required are courses in the appropriate subject matter meeting State guidelines as defined in Massachusetts regulations (603 CMR 7.00). Students wishing to discuss or pursue this should see Professor John Goulet (MA) and/or see http://users.wpi.edu/~goulet/teacher_prep/teacher_prep.htm.

INTERNATIONAL STUDIES

DIRECTOR: P. H. HANSEN
ASSOCIATED FACULTY: W.A.B. Addison (HU), U Brisson (HU), F. Carrera (IGSD), D.B. Dollemeyer (HU), A. Gerstenfeld (MG), D. Golding (IGSD), P.H. Hansen (HU), R. Hersh (IGSD), S. Jiusto (IGSD), R. Krueger (IGSD), I. Matos-Nin (HU), C. Peet (IGSD), M.J. Radzicki (SSPS), K.J. Rissmiller (SSPS), A. Rivera (HU), T. Robertson (HU), J. Rudolph (HU), K. Saeed (SSPS), S. Tuler (IGSD), R. Vaz (IGSD; ECE), S. Vernon-Gerstenfeld (IGSD)

International Studies prepares men and women for future leadership roles in business and industry, government and public affairs. International Studies integrates WPI's international courses in the humanities and social sciences with its global projects and exchange programs. International 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 Studies at WPI offers a range of options including a minor, major, or double major in International Studies.

Program Requirements for the International Studies Minor

INTERNATIONAL STUDIES IQP OPTION

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INTERNATIONAL STUDIES EXCHANGE PROGRAM OPTION

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<td>International Experience (Note 4)</td>
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</tr>
<tr>
<td><strong>Total</strong></td>
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</tr>
</tbody>
</table>

NOTES:
1. International Core. Both options require the same one unit core of international courses. One course must be selected from each of these categories:
   a) An introductory course in international history, such as HI 1341, HI 1321, HI 1322, HI 1323, or HI 1313.
   b) A course in understanding cross-cultural differences, such as one of the following: HU 3411 Pre-Seminar in Global Perspectives; PSY 2406 Cross-Cultural Psychology; SOC 1202 Introduction to Sociology and Cultural Diversity; PY 2716 Philosophy of Difference.
   c) HU 4411 Senior Seminar in International Studies.

Courses in the core may not double-count towards other degree requirements such as the Humanities and Arts Requirement requirement or the two course requirement in the Social Sciences. If a student has already counted a course such as the Humanities and Arts Requirement requirement or the two course requirement in the Social Sciences, they will be required to take additional courses in International Studies so that at least one unit of their minor does not double-count. The capstone seminar should be the final element of a student's minor.
2. International Electives may be selected from among international courses in the Humanities and Social Sciences. They may include any course in European or global history; any course at the intermediate level or above in German or Spanish; any international course in the social sciences; and international courses approved by the Program Review Committee in art history, literature, philosophy and religion. If approved by the Program Review Committee, PQPs for overseas projects may count towards the total. Students may count courses taken to fulfill other degree requirements towards these electives. These electives may not include the MQP.

3. International IQP: Students who choose the IQP Option must complete an International IQP. All IQPs completed outside of the United States meet this requirement. If approved by the Program Review Committee, IQPs completed on-campus or at Project Centers in the United States may meet this requirement if the IQP is devoted to an international subject and the student also completes a study abroad experience as described in note 4.

4. International Experience: All International Studies minors are required to have a study abroad experience. Students who choose the Exchange Option must complete an international 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.

For general policy on the minor, see description on page 10.

### Distribution Requirements for the International Studies Major

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<th>REQUIREMENTS</th>
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<td>MQP</td>
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<tr>
<td>Total</td>
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</table>

**NOTES:**

1. International Core: One course must be selected from each of these categories:
   a) An introductory course in international history, such as HI 1341 or HI 1311, HI 1321, HI 1322, HI 1323.
   b) A course in understanding cross-cultural differences, such as one of the following: HU 3411 Pro-Seminar in Global Perspectives, or SOC 1202 Introduction to Sociology and Cultural Diversity, or PSY 2406 Cross-Cultural Psychology; or PSY 2716 Philosophy of Difference.
   c) HU 4411 Senior Seminar in International Studies.

2. International 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) Historical Analysis. These include any courses in European history, world history, or American foreign policy.
   b) Language, Literature, and Culture. These include any course in foreign languages, civilization, and literature offered at WPI 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 2111), English Literature (e.g. EN 2243, EN 3222), Music History (e.g. MU 2615), or Philosophy and Religion (e.g. RE 2721, RE 2724). Majors who designate Language, Literature, and Culture (LLC) as their primary field may not take courses in a second foreign language unless they have achieved 3000-level proficiency in the first. LLC designees should take most of their courses in a single discipline or in a coherent program approved by the Program Review Committee.
   c) Social Sciences. These include international courses in the social sciences (e.g. GOV 1320, ECON 2125, GOV 2312, PSY 2406). 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 1/3 unit in science, 1/3 unit in mathematics, 1/3 unit in computer science or engineering science. The remaining 1 unit may be from science, mathematics, computer science or engineering. 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 STUDIES

Students may pursue a double major in International 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. In addition, the double major in International Studies requires the same distribution of courses in the International Core and International Fields as the major in International Studies and a second MQP in International Studies. Double majors are also required to have an International Experience. Students pursuing the double major in International Studies are not required, however, to complete a Humanities and Arts program.

### INTERNATIONAL EXPERIENCES

An International Experience may take the form of an international IQP or exchange program. Students often plan their international 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 186.

Award-winning projects at WPI are frequently on international topics. Recent examples include studies of a workshop for the blind in London, chemical accidents in Bangkok, the social impact of the building code in New Zealand, and the use of biogas in Botswana. International 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 Studies may ask any member of the Associated Faculty for more information, or they may consult our page on the World Wide Web: http://www.wpi.edu/INTERNATIONAL/.

### LAW AND TECHNOLOGY MINOR

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. Students complete their studies with a capstone research activity either in the sixth course or as a separate independent study.

To attain a Minor in Law and Technology, students must complete two units of study (6 courses) as follows:

1. Two of the following courses in legal fundamentals:
   - HI 2317 Law and Society in America, 1865-1910
   - GOV 1310 Law, Courts and Politics
   - GOV 2311 Constitutional Law: Foundations
   - GOV 2320 Constitutional Law: Civil Rights and Liberties
   - BUS 2950 Business Law and Ethics

2. Two of the following courses which integrate law and technology:
   - CE 3022 Legal Aspects in Design and Construction
   - CE 4071 Land Use Development and Controls
   - GOV 2302 Science-T echnology Policy
   - GOV 2311 Environmental Policy and Law
   - GOV 2313 Intellectual Property Law
   - GOV-ID 2314 Cyberlaw and Policy
   - Independent study or experimental courses with the approval of the pre-law advisor

3. One of the following courses in professional communication:
   - EN/WR 2210 Introduction to Professional Writing
   - EN/WR 2211 Elements of Writing
   - EN/WR 3214 Writing About Disease and Public Health
   - RH 3112 Rhetorical Theory

4. One of the following courses undertaken as a capstone experience:
   - GOV 2304 Governmental Decision Making and Administrative Law
   - GOV 2312 International Environmental Policy

If a student takes both GOV 2304 and GOV 2313, the first one taken will count among courses that integrate law and technology, point 2., above. Minors enrolled in either course for their capstone experience will be required to complete the usual course requirements and an additional research paper. In the paper, the student will summarize existing law in an area of student interest, identify problems with the law, evaluate proposals for change and recommend legislative changes. As an alternative, students may complete the capstone requirement as an independent study (IS/P) course with the approval and participation of one of the associated faculty.

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 52, Law and Technology. See page 16. Note: only one of the two units may be counted toward other college requirements.

For general policy on the Minor, see description on page 10.

LIBERAL ARTS AND ENGINEERING
(BACHELOR OF ARTS DEGREE)

DIRECTORS: J. ORR (ECE), L. SCHACHTERLE (HU)
ASSOCIATED FACULTY and PROGRAM COMMITTEE:
D. DiBiasio (ChE), J. Doyle (SSPS), P. Hansen (HU),
S. Juisto (IGSD), R. Krueger (IGSD), K. Rissmiller (IGSD and
SSPS), D. Samson (HU), G. Tryggvason (ME),
R. Vaz (IGSD and ECE)

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 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 minimal loss of time.

For more information, see the Admissions web site at http://www.wpi.edu/Academics/Majors/LAE/index.html.

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 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 music and theatre
• 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
### Table 1: BA in Liberal Arts and Engineering

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<td>18 Math &amp; Science</td>
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<td>23 Math &amp; Science</td>
<td>PH 1120</td>
<td>BB 1002</td>
<td>PH 1110</td>
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<td>24 Math &amp; Science</td>
<td>BB 1001</td>
<td>PH 1110</td>
<td>PH 1120</td>
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<tr>
<td>Engineering Studies Cornerstone (3 Units)</td>
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<tr>
<td>26 Engineering Sci/Des</td>
<td>ECE 2022</td>
<td>ES 3003</td>
<td>ES 1310</td>
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<tr>
<td>28 Engineering Sci/Des</td>
<td>ECE 2311</td>
<td>ES 2501</td>
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<td>29 Engineering Sci/Des</td>
<td>ECE 2201</td>
<td>ECE 2011</td>
<td>ES 2502</td>
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<td>30 Engineering Sci/Des</td>
<td>ECE 2801</td>
<td>ECE 2111</td>
<td>ES 2503</td>
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<td>31 Engineering Sci/Des</td>
<td>ECE 2112</td>
<td>ECE 3501</td>
<td>ES 3003</td>
</tr>
<tr>
<td>32 Engineering Sci/Des</td>
<td>ECE 2799 (design)</td>
<td>ME 2300 (design)</td>
<td>ME 2300 (design)</td>
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<tr>
<td>33 Engineering Sci/Des</td>
<td>CS 1101</td>
<td>CS 1101</td>
<td>CS 1101</td>
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<tr>
<td>Liberal Arts Cornerstone (3 Units)</td>
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<tr>
<td>34 Liberal Studies</td>
<td>PY 2714 Ethics in the Professions</td>
<td>PY 2717 Phil. &amp; Environ.</td>
<td>GOV 1303 American Pub. Policy</td>
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<tr>
<td>35 Liberal Studies</td>
<td>HI 1332 History of Technology</td>
<td>GOV 2311 Ev. Policy &amp; Law</td>
<td>GOV 1310 Law, Courts, Politics</td>
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<tr>
<td>36 Liberal Studies</td>
<td>HI 3331 Topics in Society/Technology Studies</td>
<td>PSY 2405 EV Problems &amp; Human Cognition</td>
<td>GOV 2313 Intellectual Property Law</td>
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<tr>
<td>37 Liberal Studies</td>
<td>STS 2208 Society-Technology Debate</td>
<td>GOV 2312 International EV Policy</td>
<td>GOV 2314 Cyberlaw and Policy</td>
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<tr>
<td>38 Liberal Studies</td>
<td>GOV 2302 Science and Technology Policy</td>
<td>HI 3333 American Tech. Development</td>
<td>GOV 2304 Govt, Decision making and Admin Law</td>
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<td>39 Liberal Studies</td>
<td>STS 1207 Introduction to the Psycho-Sociology of Science</td>
<td>GOV 2302 Science and Technology Policy</td>
<td>STS 1207 Introduction to the Psycho-Sociology of Science</td>
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<td>40 Liberal Studies</td>
<td>OIE 2850 Engineering Economics</td>
<td>OIE 2850 Engineering Economics</td>
<td>BUS 2950 Bus Law &amp; Ethics</td>
</tr>
<tr>
<td>41 Liberal Studies</td>
<td>BUS 2950 Business Law and Ethics</td>
<td>BUS 2950 Business Law &amp; Ethics</td>
<td>OIE 2850 Eng’g Economics</td>
</tr>
</tbody>
</table>

| MQP – aimed at confluence of engineering and liberal arts cornerstones (1 Unit) |
|---------------------------------|-----------------|-----------------|
| 43 MQP  | MQP  | MQP  |
| 44 MQP  | MQP  | MQP  |
| 45 MQP  | MQP  | MQP  |
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

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics and Basic Sciences (Notes 1, 2)</td>
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<tr>
<td>2. Engineering Science and Design (Notes 3, 4, 5)</td>
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</tr>
<tr>
<td>3. Humanities and Arts, Social Science, and Management Topics (Notes 6, 7)</td>
<td>3</td>
</tr>
<tr>
<td>4. MQP (Note 8)</td>
<td>1</td>
</tr>
</tbody>
</table>

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 Unit each of BB, CH, and PH.
3. Courses with prefixes 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, 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.
7. May include up to 1 Unit of Management. 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 Management 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.

MANAGEMENT

M.C. BANKS, HEAD
A.Z. ZENG, DIRECTOR IE PROGRAM
D.M. STRONG, DIRECTOR MIS PROGRAM

ASSISTANT PROFESSORS: S. Djamasbi, R. Konrad, F. Miller, B. Tulu, J. Wang, W. Zhao

PROFESSOR OF PRACTICE: J. Schaufeld

The Department of Management at WPI is the nationally ranked business school at WPI. Those rankings derive partially from the project enriched curriculum required of all WPI undergraduate students, as well as the emphasis on innovation, entrepreneurship, and technology that is found throughout the Department’s undergraduate and graduate programs.

MISSION STATEMENT
The Department of Management at WPI is rooted in WPI’s strengths in technology, engineering, and science, and known for developing innovative and entrepreneurial leaders for a global technological world. We focus on:
• Creating and leading technology-based organizations;
• Innovating technology based processes, products, and services; and
• Integrating technology into the workplace.
We emphasize:
• Innovative and project-based education that integrates the theory and the practice of management, and prepares students to assume positions of leadership in an increasingly global business environment;
• Basic scholarship, while also valuing the scholarship of application and the scholarship of instruction; and
• Interaction with the wider community focused primarily on technological innovation and both individual and organizational entrepreneurship.
COURSE AREAS
The Department of Management covers all the functional areas of business. Courses with the following prefixes are found in the Department:

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

MANAGEMENT (MG)

PROGRAM EDUCATIONAL OBJECTIVES
Objectives of the Management 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 Management Major

<table>
<thead>
<tr>
<th>REQUIREMENTS (NOTE 1)</th>
<th>MINIMUM UNITS</th>
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</thead>
<tbody>
<tr>
<td>1. Business Foundation (Note 2)</td>
<td>11/3</td>
</tr>
<tr>
<td>2. Mathematics (Note 3)</td>
<td>4/3</td>
</tr>
<tr>
<td>3. Basic Science</td>
<td>2/3</td>
</tr>
<tr>
<td>4. Management Major (Note 4)</td>
<td>6/3</td>
</tr>
<tr>
<td>5. Breadth Electives (Note 5)</td>
<td>3/3</td>
</tr>
<tr>
<td>6. Computer Science (Note 6)</td>
<td>1/3</td>
</tr>
<tr>
<td>7. MG MQP</td>
<td>3/3</td>
</tr>
</tbody>
</table>

NOTES:
1. Courses may not be counted more than once in meeting these distribution requirements. The total number of units taken in the Department of Management may not exceed 50% of the total number of units earned for the degree.


3. Mathematics must include 2/3 units of calculus and 2/3 units of statistics.
4. Students selecting the Management Major must complete six courses from no more than three areas listed below:
   ACCOUNTING & FINANCE: ACC 4151, FIN 2250, FIN 2260
   ENTREPRENEURSHIP: ETR 3633, ETR 3910, ETR 3920, ETR 4930
   MARKETING: MKT 3640, MKT 3651
   ORGANIZATIONAL BEHAVIOR: OBC 3351, OBC 4364, OBC 4365, OBC 4300
   ECONOMICS: ECON 1130, ECON 2110, ECON 2117, ECON 2120, ECON 2125, ECON 2135
   LAW: GOV 1310, GOV 2304, GOV 2310, GOV 2311, GOV 2312, GOV 2313, GOV 2314
   PSYCHOLOGY: PSY 1401, PSY 1402, PSY 1504, PSY 2406

Additionally, the MQP must be related in some way to the courses taken. Students may also work with their academic advisor to create a custom MG Program. Such custom programs must be approved by the advisor and the Department of Management’s Undergraduate Policy & Curriculum Committee.

5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the Department. 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, but excluding courses FIN 1250 and OIE 2850.

6. A minimum of 1/3 unit of Computer Science (except CS 2022 and CS 3043). Either CS 1101 or CS 1102 is recommended.

MANAGEMENT ENGINEERING (MGE)

EDUCATIONAL PROGRAM 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

<table>
<thead>
<tr>
<th>REQUIREMENTS (NOTE 1)</th>
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</thead>
<tbody>
<tr>
<td>1. Business Foundation (Note 2)</td>
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<td>2. Mathematics (Note 3)</td>
<td>4/3</td>
</tr>
<tr>
<td>3. Basic Science</td>
<td>2/3</td>
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<td>4. Management Engineering Major (Note 4)</td>
<td>6/3</td>
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<tr>
<td>5. Breadth Electives (Note 5)</td>
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<tr>
<td>6. Computer Science (Note 6)</td>
<td>1/3</td>
</tr>
<tr>
<td>7. MGE MQP</td>
<td>3/3</td>
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</tbody>
</table>

NOTES:
1. Courses may not be counted more than once in meeting these distribution requirements. The total number of units taken in the Department of Management may not exceed 50% of the total number of units earned for the degree.
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 below:

**Operations Management Concentration – 2 units**
- Complete the following **four** courses
  - OBC 3351
  - OIE 3401
  - OIE 3420
  - OIE 4460

**and** Select two courses from among:
- ACC 4151
- CS 2118
- MIS 3720
- MKT 3640
- OBE 4365
- OIE 3501

The MQP must have an Operations Management focus.

**Biomedical Engineering Concentration – 2 units**
- Complete at least one course, but no more than two, from among:
  - BUS 1900
  - ETR 3910
  - ETR 3920
  - ETR 4930
  - MKT 3640
  - MKT 3651
  - OIE 3401
  - OIE 3420
  - OIE 3501
  - OBC 3351
  - OBC 4365

**and** Select at least four courses, but no more than five, from among:
- BME 1001
- BME 2204
- BME 2504
- BME 2604
- BME 3101
- BME 3102
- BME 3300

The MQP must have a business focus related to Biomedical Engineering.

**Chemistry Concentration – 2 units**
- Complete at least one course, but no more than two, from among:
  - BUS 1900
  - ETR 3910
  - ETR 3920
  - ETR 4930
  - MKT 3640
  - MKT 3651
  - OIE 3401
  - OIE 3420
  - OIE 3501
  - OBC 3351
  - OBC 4365

**and** Select at least four courses, but no more than five, from among:
- CH1030
- CH1040
- CH2310
- CH2320
- CH2330
- CH2360
- CH2640
- CH3510

The MQP must have a business focus related to Chemistry.

Students pursuing the Chemistry Concentration must complete CH1010 and CH1020 for their basic science requirement. This may not be double counted as part of the Chemistry Concentration.

**Civil Engineering Concentration – 2 units**
- Complete at least one course, but no more than two, from among:
  - BUS 1900
  - ETR 3910
  - ETR 3920
  - ETR 4930
  - MKT 3640
  - MKT 3651
  - OIE 3401
  - OIE 3420
  - OIE 3501
  - OBC 3351
  - OBC 4365

**and** Select at least four courses, but no more than five, from among:
- CE 1030
- CE 2000
- CE 2001
- CE 2020
- CE 3030
- CE 3041
- ES 3004

The MQP must have a business focus related to Civil Engineering.

**Electrical and Computer Engineering Concentration – 2 units**
- Complete at least one course, but no more than two, from among:
  - BUS 1900
  - ETR 3910
  - ETR 3920
  - ETR 4930
  - MKT 3640
  - MKT 3651
  - OIE 3401
  - OIE 3420
  - OIE 3501
  - OBC 3351
  - OBC 4365

**and** Select at least four courses, but no more than five, from among:
- ECE 2011
- ECE 2022
- ECE 2111
- ECE 2112
- ECE 2311
- ECE 2312
- ECE 2799
- ECE 2801

The MQP must have a business focus related to Electrical and Computer Engineering.

**Mechanical Engineering Concentration – 2 units**
- Complete at least one course, but no more than two, from among:
  - BUS 1900
  - ETR 3910
  - ETR 3920
  - ETR 4930
  - MKT 3640
  - MKT 3651
  - OIE 3401
  - OIE 3420
  - OIE 3501
  - OBC 3351
  - OBC 4365

**and** Select at least four courses, but no more than five, from among:
- ES 2001
- ES 2501
- ES 2502
- ES 2503
- ES 3001
- ES 3003
- ES 3004
- ME 1800
- ME 2300
- ME 2820
- ME 3820
- ME 3901
- ME 4320
- ME 4429
- ME 4430

The MQP must have a business focus related to Mechanical Engineering.

**Manufacturing Engineering Concentration – 2 units**
- Complete at least one course, but no more than two, from among:
  - BUS 1900
  - ETR 3910
  - ETR 3920
  - ETR 4930
  - MKT 3640
  - MKT 3651
  - OIE 3401
  - OIE 3420
  - OIE 3501
  - OBC 3351
  - OBC 4365

**and** Select at least four courses, but no more than five, from among:
- ES 2001
- ME 1800
- ME 2820
- ME 3320
- ME 3820
- ME 4815
- ME 487x
- ME 489x

The MQP must have a business focus related to Manufacturing Engineering.

Students may also work with their academic advisor to create a custom MGE Program. Such custom programs must be approved by the advisor and the Department of Management’s Undergraduate Policy & Curriculum Committee.
Business Foundation Chart

**Freshman and Sophomore Courses**
- ECON 1110 and ECON 1120
- BUS 1010 Leadership Practice
- BUS 1020 Global Environment of Business Decisions
- 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

**I. Business Context and Mindsets Cluster**
- Humanities & Arts (6 courses)

**II. Business Managerial Tools Cluster**
- STEM Courses (2 Calc, 2 Stat, 2 Sci, 1 CS)

**Junior and Senior Courses**
- BUS 3010 Creating Value through Innovation
- BUS 3020 Achieving Effective Operations
- BUS 4030 Achieving Strategic Effectiveness

**III. Business Execution Cluster**
- BUS 2080 Data Analysis for Decision Making
- PE (4 courses)
- Free Electives (5 courses)
- Breadth Electives (3 courses)
- MAJOR (6 courses)

New Undergraduate Business Foundation (effective fall 2010)
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the Department. 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, but excluding courses FIN 1250 and OIE 2850.

6. A minimum of 1/3 unit of Computer Science (except CS 2022 and CS 3043). Either CS 1101 or CS 1102 is recommended.

**MANAGEMENT INFORMATION SYSTEMS (MIS)**

**EDUCATIONAL PROGRAM 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 networked 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**

<table>
<thead>
<tr>
<th>REQUIREMENTS (NOTE 1)</th>
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<td>4. Management Information Systems Major (Note 4)</td>
<td>6/3</td>
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<td>5. Breadth Electives (Note 5)</td>
<td>3/3</td>
</tr>
<tr>
<td>6. Computer Science (Note 6)</td>
<td>1/3</td>
</tr>
<tr>
<td>7. MIS MQP</td>
<td>3/3</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Courses may not be counted more than once in meeting these distribution requirements. The total number of units taken in the Department of Management may not exceed 50% of the total number of units earned for the degree.


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 below:

   - Complete the following four courses: MIS 3720, MIS 3740, MIS 4720, and CS 2118.
   - Complete two of the following courses: MIS 4740, MIS 4781, CS 2102, CS 2301 or CS 2303, CS 3041.
   - Complete a MQP in MIS.

   Students may work with their academic advisor to create a custom MIS Program. Such custom programs must be approved by the advisor and the Department of Management's Undergraduate Policy & Curriculum Committee.

5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the Department. 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, but excluding courses FIN 1250 and OIE 2850.

6. A minimum of 1/3 unit of Computer Science (except CS 2022 and CS 3043). Either CS 1101 or CS 1102 is recommended.

**ENTREPRENEURSHIP MINOR**

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 the Robert H. Grant Invention Awards, the Henry Strage Innovation Awards, the CEI @ WPI ALL-OUT Business Plan Competition, the WPI Dinner with Entrepreneurs Series, the WPI chapter of CEO (Collegiate Entrepreneurs Organization), several conferences, many workshops, the monthly WPI Venture Forum meetings, a variety of speakers and other events related to entrepreneurship, and access to a wide network of entrepreneurs from around the U.S. and abroad.

The Minor in Entrepreneurship is available to all students except those majoring in MG, MGE, or MIS, who may take the courses as part of their major or as Breadth or Free Electives.
The minor requires the completion of two units of course-work as noted below.

1. Complete the following course:
   OIE 2850 Engineering Economics

2. Complete two (2) from the following list:
   - ACC 1100  Financial Accounting OR
   - ACC 2101  Management Accounting
   - BUS 2950  Business Law & Ethics
   - OIE 3400  Production System Design
   - MKT 3600  Marketing Management
   - MIS 3700  Information Systems Management

3. Complete the following three courses, preferably in order:
   - ETR 3910  Identifying & Evaluating New Venture Opportunities
   - ETR 3920  Planning & Launching New Ventures
   - ETR 4930  Growing and Managing New Ventures

As noted above, students majoring in MG, MGE, or MIS may not minor in Entrepreneurship.

For general policy on the Minor, see the description on page 10.

MIS MINOR

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 (other than MG, 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 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. One course from the group of courses:
   - BUS 1900  Introduction to Business in an International Environment OR
   - ACC 1100  Financial Accounting OR
   - ACC 2101  Management Accounting OR
   - OBC 2300  Organizational Science

2. Two courses, or their equivalents, from the following list:
   - CS 1101  Introduction to Program Design OR
   - CS 1102  Accelerated Introduction to Program Design
   - CS 2118  Object-Oriented Design Concepts for Business Applications
   - CS 2301  Systems Programming for Non-Majors OR
   - CS 2303  Systems Programming Concepts

3. Two courses from the group of courses:
   - MIS 3700  Information Systems Management
   - MIS 3720  Management of Data
   - MIS 3740  Organizational Application of Telecommunications

4. Capstone Experience
   - MIS 4720  Systems Analysis and Design
   - Course MIS 4720 is a project-oriented course designed to prepare MIS students and minors for actual information systems design work in business and industry. The course builds and uses MIS concepts for the sound and efficient design of information systems.

   Students majoring in MG, MGE, or MIS may not take the MIS Minor.

   For general policy of the Minor, see the description on page 10.
ORGANIZATIONAL LEADERSHIP MINOR

One of the critical elements for any person who hopes to succeed in a formal organization is leadership. While some people come by their organizational leadership abilities instinctively or by learning from others at an early age, many others come late to their leadership talents and still others never realize their leadership abilities. It is the purpose of the Department of Management’s Organizational Leadership minor to provide students with the theoretical underpinnings of leadership and, in keeping with a WPI education, the knowledge of how that theory applies to practice. Thus, through this minor students will be able to understand and apply leadership theories to their lives and, in the process, make themselves more marketable upon graduation.

The minor in Organizational Leadership consists of three primary components. These components are a choice of Management courses, a choice among three Social Science & Policy Studies courses, and a capstone course in Leadership.

1. Select four of the following:
   - BUS 1900 Introduction to Business in an International Environment
   - OBC 2300 Organizational Science - Foundation
   - BUS 2950 Business Law & Ethics
   - OBC 3351 Organizational Science - Management of Change
   - OBC 4364 Human Resource Management

2. Select one of the following:
   - PSY 1401 Cognitive Psychology
   - PSY 1402 Social Psychology
   - PSY 2406 Cross-Cultural Psychology: Human Behavior in Global Perspective

3. Required Capstone Experience
   - OBC 4365 Leadership in Groups and Organizations

Note: The minor in Organizational Leadership may not be taken by students majoring in MG, MGE, or MIS. These students may take the courses as part of their major or as Breadth or Free Electives, as appropriate.

For general policy on the Minor, see the description on page 10.
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;

### 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:

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
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</thead>
<tbody>
<tr>
<td>1. Mathematics including MQP (See notes 1-4)</td>
<td>7</td>
</tr>
<tr>
<td>2. Courses from other departments that are related to the student's mathematical program. At least 2/3 unit in computer science must be included; the remaining courses are to be selected from science, engineering, computer science or management (except MG 1250) (see Note 5).</td>
<td>2</td>
</tr>
<tr>
<td>3. Additional courses or independent studies (except MS, PE courses, and other degree requirements) from any area.</td>
<td>1</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Must include MA 3831-3832, 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.
4. May not include both MA 2631 and MA 2621.
5. May not include both CS 3043 and CS 2022.

### 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. Students 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.

In what follows, you will find 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 skill is growing in importance and should be a part of every applied mathematician's training. 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.

<table>
<thead>
<tr>
<th>Courses of Interest</th>
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<tbody>
<tr>
<td>MA 2251 Vector and Tensor Calculus</td>
</tr>
<tr>
<td>MA 2431 Mathematical Modeling with Ordinary Differential Equations</td>
</tr>
<tr>
<td>MA 3231 Linear Programming</td>
</tr>
<tr>
<td>MA 3257 Numerical Methods for Linear and Nonlinear Systems</td>
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<tr>
<td>MA 3457 Numerical Methods for Calculus and Differential Equations</td>
</tr>
<tr>
<td>MA 3471 Advanced Ordinary Differential Equations</td>
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<td>MA 3475 Calculus of Variations</td>
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<tr>
<td>MA 4235 Mathematical Optimization</td>
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<tr>
<td>MA 4291 Applicable Complex Variables</td>
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<tr>
<td>MA 4411 Numerical Analysis of Differential Equations</td>
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<tr>
<td>MA 4451 Boundary Value Problems</td>
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<tr>
<td>MA 4473 Partial Differential Equations</td>
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### Mathematical Sciences Major Program Chart

#### University Requirements

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<td>Physical Education</td>
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#### Foundation Courses

**Introductory Courses**

- MA 1021-1024 or MA 1031-1034
- MA 2051
- MA 2071
- MA 2201
- MA 2251
- MA 2611

#### Transition Courses (1 Unit Required)

- MA 2073
- MA 2271*
- MA 2273*
- MA 2431
- MA 2631

#### Core Courses (4/3 Unit Required)

- Both MA 3831 and MA 3832
- One of MA 3257 or MA 3457
- One of MA 3823* or MA 3825*

### Other MA Courses to Attain Total of 6 Units:

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### Other Requirements

- Computer Science Courses 2/3 Unit

* Category II courses, offered in alternating years.
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<th>ALGEBRA</th>
<th>DISCRETE MATH</th>
<th>COMPUTATIONAL MATH</th>
<th>OPERATIONS RESEARCH</th>
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<th>OTHER REQUIREMENTS</th>
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<tr>
<td>Computer Science (2/3 Unit Required)</td>
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* Category II courses, offered in alternating years.
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 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

MA 2271 Graph Theory
MA 2273 Combinatorics
MA 3231 Linear Programming
MA 3233 Discrete Optimization
MA 3627 Applied Statistics III
MA 3631 Mathematical Statistics
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 2500 Management Science I: Deterministic Decision Models
OIE 3460 Simulation Modeling and Analysis
OIE 3501 Management Science II: Risk Analysis

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
MA 3627 Applied Statistics III
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

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, Allmerica Financial, Blue Cross Blue Shield of Massachusetts, John Hancock Mutual Insurance, Premier Insurance, and Travelers Property Casualty. 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**  
1. Mathematics (including MQP) (See notes 1-6).  
2. Management (See note 7).  
3. Additional courses or independent studies (except MS, PE courses, and other degree requirements) from any area (See note 8).

**MINIMUM UNITS**  
1. Mathematics (including MQP) (See notes 1-6).  
2. Management (See note 7).  
3. Additional courses or independent studies (except MS, PE courses, and other degree requirements) from any area (See note 8).

**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 3631, MA 4632, 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 3211, MA 3212, MA 4213, MA 4214, or their equivalents.
4. May not include independent studies directed toward Society of Actuaries exams.
5. May not include either MA 2201 or MA 2210.
6. May not include both MA 2631 and MA 2621.
7. Must include ACC 2101 and FIN 2200 or their equivalents.
8. Must include 2/3 units of computer science.

Students interested in pursuing a degree in Actuarial Mathematics should contact Professor Abraham, the Coordinator of the Actuarial Mathematics Program, as soon as possible.

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**STATISTICS MINOR**

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 following requirements must be satisfied.

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, or
   - MA 2621 Probability for Applications

   **Upper-Level Courses (2/3 Unit Required)**
   - MA 3627 Applied Statistics III
   - 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

   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 the instructor. This is done 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.

   Here are some examples of 5/3 units of coursework for four thematically-related minors. Other options are available.

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For more information about the Mathematics minor, see Professor Farr, who is the coordinator for Mathematics minors.
MECHANICAL ENGINEERING

G. TRYGGVASON, HEAD


ASSISTANT PROFESSORS: S. Evans, G. Fischer, I. Hussein, D. Lados, J. Liao, S. Nestinger, J. Van de Ven

VISITING ASSISTANT PROFESSOR: E. C. Cobb


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 the design process.
• 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 society for the betterment of humankind.

PROGRAM OUTCOMES

Graduating students should demonstrate that they attain the following:

• an ability to apply knowledge of mathematics, science, and engineering
• an ability to design and conduct experiments, as well as to analyze and interpret data
• an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
• an ability to function on multi-disciplinary teams
• an ability to identify, formulate, and solve engineering problems
• an understanding of professional and ethical responsibility
• an ability to communicate effectively

• the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
• a recognition of the need for, and an ability to engage in lifelong learning
• a knowledge of contemporary issues
• an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
• an ability to apply principles of engineering, basic science, and mathematics (including multivariate calculus and differential equations) to model, analyze, design, and realize physical systems, components or processes
• an ability to work professionally in both thermal and mechanical systems areas

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) | 4
2. Engineering Science and Design (includes MQP) (Notes 3, 4, 5, 6, 7, 8, 9) | 6

**NOTES:**

1. Must include a minimum of 5/3 units of mathematics, including differential and integral calculus and differential equations.
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 an activity that involves basic matrix algebra and the solution of systems of linear equations, and an activity that involves data analysis and applied statistical methods.
4. Must include 1/3 unit in each of the following: electrical engineering, materials science, and mechanical engineering experimentation.
5. Must include at least one unit of ME courses at the 4000-level.
6. May include 1000 level courses only if designated ES or ME.
7. Must include two stems of coherent course and/or project offerings as noted below in a and b.
   a. A minimum of one unit of work in thermofluid systems that includes the topics of thermodynamics, fluid mechanics and heat transfer, plus an activity that integrates thermofluid design.
   b. A minimum of one unit of work in mechanical systems that includes the topics of statics, dynamics, and stress analysis, plus an activity that integrates mechanical design.
8. Must include an activity which realizes (constructs) a device or system.
9. Must include 1/3 unit of Capstone Design Experience. Items 3, 5, 7a integration, 7b integration, 8, 9 may all be “multiple-counted.”

Each Mechanical Engineering student must complete a Capstone Design experience requirement. This capstone design experience is 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
STUDENTS EARNING A B.S. DEGREE IN MECHANICAL ENGINEERING MUST COMPLETE 15 UNITS OF STUDY, DISTRIBUTED ASollows:

4 UNITS OF NON-TECHNICAL ACTIVITIES

<table>
<thead>
<tr>
<th>2 UNITS HUMANITIES AND ARTS</th>
<th>See WPI Requirements</th>
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</thead>
<tbody>
<tr>
<td>1 UNIT INTERACTIVE QUALIFYING (IQP) PROJECT</td>
<td>See WPI Requirements</td>
</tr>
<tr>
<td>2/3 UNIT SOCIAL SCIENCE</td>
<td>See WPI Requirements</td>
</tr>
<tr>
<td>1/3 UNIT PHYSICAL EDUCATION</td>
<td>See WPI Requirements</td>
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1 UNIT FREE ELECTIVE

4 UNITS OF MATHEMATICS AND BASIC SCIENCE

<table>
<thead>
<tr>
<th>5/3 Units</th>
<th>Differential &amp; Integral Calculus and Ordinary Differential Equations</th>
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<tbody>
<tr>
<td>3/3 Units</td>
<td>One Chemistry and Two Physics, OR One Physics and Two Chemistry</td>
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4/3 Units
Student Selected Courses from the General Category of Mathematics and/or Basic Science

6 UNITS OF MECHANICAL ENGINEERING (Notes 1 & 2)

<table>
<thead>
<tr>
<th>1 unit required</th>
<th>1 unit required</th>
<th>1 unit required</th>
<th>1 unit required</th>
<th>2 units required</th>
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</thead>
<tbody>
<tr>
<td>MECHANICAL SYSTEMS</td>
<td>THERMOFLUID SYSTEMS</td>
<td>OTHER COURSES</td>
<td>MAJOR QUALIFYING PROJECT (MQP)</td>
<td>ELECTIVES</td>
</tr>
<tr>
<td>ES 2501</td>
<td>ES 3001</td>
<td>ES 2001</td>
<td></td>
<td>At least one unit must be chosen as ES or ME courses at the 4000-level or higher.</td>
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<tr>
<td>ES 2502</td>
<td>ES 3003</td>
<td>ECE 3601</td>
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<tr>
<td>ES 2503</td>
<td>ES 3004</td>
<td>ME 3901</td>
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The courses listed above can be replaced by other equivalent courses, with approval by the ME Program Committee.

Note 1: A complete program must include an activity in each of the following six categories. Courses used to satisfy these activities can be multiple-counted. They can be used to simultaneously satisfy the mechanical engineering, mathematics and basic science, and free elective requirements.

### OTHER ACTIVITIES

<table>
<thead>
<tr>
<th>Linear Algebra</th>
<th>Statistics</th>
<th>Mechanical System Design</th>
<th>Thermofluid System Design</th>
<th>Realization</th>
<th>Capstone Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 2071 ME 3501</td>
<td>MA 2611</td>
<td>ME 3310 ME 4320</td>
<td>ME 4429</td>
<td>ES 3323</td>
<td>ME 4320</td>
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<tr>
<td>MA 2073 ME 4505</td>
<td>MA 2612</td>
<td>ME 3311 ME 4430</td>
<td>ME 4430</td>
<td>ME 1800</td>
<td>ME 4429</td>
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<tr>
<td>MA 4411 ME 4512</td>
<td>MA 2621</td>
<td>ME 3320 ME 4770</td>
<td>ME 4770</td>
<td>ME 2300</td>
<td>ME 4430</td>
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<tr>
<td>ME 3311 ME 3321</td>
<td>ME 3901</td>
<td>ME 3506 ME 4771</td>
<td>ME 4771</td>
<td>ME 3506</td>
<td>ME 4770</td>
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<td></td>
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<td>MQP (depending on topic)</td>
<td>MQP (depending on topic)</td>
<td>MQP</td>
<td>ME 4810</td>
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<td>MQP</td>
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</table>

Note 2: Elective courses from other engineering disciplines may also be selected at the 2000, 3000 or 4000 levels.
whether the MQP will meet the Capstone Design requirement or not. If not, the advisor will identify an additional 1/3 unit of course work in the area of design (ME 4320, ME 4429, ME 4430, ME 4770, or ME 4810) to be taken in order to meet the ABET Capstone Design requirement.

MECHANICAL ENGINEERING DEPARTMENT CONCENTRATIONS

AERONAUTICS (GATSONIS)
Students are provided with ample opportunity to develop technical competence in low- and high-speed aerodynamics, aircraft propulsion systems, structures, and aircraft design. Experimental and computational facilities are available for course and projects. Typical MQPs include: the design, construction, and testing of remotely piloted aircraft and micro aerial vehicles; experimental and computational aerodynamics; flow and structural control; parachute aerodynamics.

Aeronautics
2 Courses Required
ME 3410 Compressible Fluid Dynamics
ME 3711 Aerodynamics

4 Courses Selected
ME 3712 Aerospace Structures
ME 4710 Gas Turbines for Propulsion and Power Generation
ME 4718 Advanced Materials with Aerospace Applications
ME 4723 Aircraft Dynamics and Controls
ME 4733 Guidance, Navigation and Communication
ME 4770 Aircraft Design

*Plus Aeronautics related MQP

ASTRONAUTICS (GATSONIS)
Students are provided with ample opportunity to develop technical competence in spacecraft dynamics, rocket propulsion, guidance and controls, space structures, and space systems design. Experimental and computational facilities are available for course and projects. Typical MQPs include: design and testing of recoverable rockets; experiments in electric propulsion and micro-propulsion; experiments in formation flying and spacecraft control.

Astronautics
2 Courses Required
ME 2713 Astronautics
ME 4713 Spacecraft Dynamics and Controls

4 Courses Selected
ME 3410 Compressible Fluid Dynamics
ME 3712 Aerospace Structures
ME 4718 Advanced Materials with Aerospace Applications
ME 4719 Rocket Propulsion
ME 4733 Guidance, Navigation and Communication
ME 4771 Spacecraft and Mission Design

*Plus Astronautics related MQP

BIOMECHANICAL (HOFFMAN)
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 4606 Biofluids
ME 4814 Biomaterials

Any BME course at the 3000-level or higher

* 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
ME 3501 Elementary Continuum Mechanics
ME 3506 Rehabilitation Engineering
ME/BME 4504 Biomechanics
ME 4505 Advanced Dynamics
ME 4506 Mechanical Vibrations
ME 4512 Introduction to the Finite Element Method

*Plus Engineering Mechanics MQP

MANUFACTURING (RONG)
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, fixtureing, machine dynamics, grinding, precision engineering, prototype manufacturing.

See also the Manufacturing Engineering degree program.

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
OIE 2850 Engineering Economics
OIE 3400 Production System Design
OIE 3401 Production Planning 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 Stoddard Laboratories.
Typical MQP topics include: X-ray diffraction, electron microscopy, computer modeling, mechanical testing and deformation mapping, plastic deformation, ceramic processing, friction, wear, corrosion, and materials processing.

Another option in the materials program is a Minor in Materials, 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 4860 Food Engineering
- ME 4875 Introduction to Nanomaterials and Nanotechnology

Any 500-level MTE course
* Plus Materials Science MQP

### MECHANICAL DESIGN (NORTON)

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 Engineering Design Graphics
- ES 3323 Introduction to CAD
- 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 (RONG)

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.

### Robotics

3 Required
- RBE 1001 Introduction to Robotics
- 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
- 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)
- ECE 2311 Continuous-Time Signal and System Analysis
- ECE 2312 Discrete-Time Signal and System Analysis
- ECE 2801 Foundations of Embedded Computer Systems
- ECE 4703 Real Time Digital Signal Processing
- CS 2102 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
- CS 4731 Computer Graphics or CS 4732 Computer Animation

*Plus Robotics MQP

*Others courses with approval from the ME Undergraduate Committee.

### THERMAL-FLUID ENGINEERING (OLINGER)

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, fluid component analysis and design, and energy storage.

### Thermal-Fluid Engineering

3 Required
- ME 3410 Compressible Fluid Dynamics
- ME 4429 Thermodynamic Applications
- ME 4710 Gas Turbines for Propulsion and Power Generation

Select 3
- ES 3002 Mass Transfer
- ME 3501 Continuum Mechanics
- ME 3711 Aerodynamics
- ME 4429 Thermodynamic Applications
- ME/BME 4606 Biofluids
- ME 4710 Gas Turbines for Propulsion and Power Generation
- ME 4719 Rocket 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 188.

MECHANICAL ENGINEERING MINOR
(FOR NON-MAJORS)
Non-ME majors interested in developing a ME minor in conjunction with their major should consult with the Department Head or the lead faculty member in the specific ME sub-area of interest to define a program leading to recognition of the minor. Each individual student minor must then be approved by the Committee on Academic Operations.

MANUFACTURING ENGINEERING MINOR
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.
   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 3400 Production System Design
   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 87). 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 h:
   CE 3026 Materials of Construction
   CH 3410 Principles of Inorganic Chemistry
   CH 2310 Organic Chemistry I
   CH 2320 Organic Chemistry II
   CH 2330 Organic Chemistry III
   CH 4330 Organic Synthesis
   CHE 3601 Chemical Materials Engineering
   ECE 4904 Semiconductor Devices
   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 Applications
   ME/BME 4814 Biomaterials
   ME 4821 Plastics
   ME 4832 Corrosion and Corrosion Control
   ME 4840 Physical Metallurgy
   ME 4860 Food Engineering
   ME 4875 Introduction to Nanomaterials and Nanotechnology
   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 508, Catalysis and Surface Science of Materials; CHE 510, Particulate Systems.

3. Capstone Experience (1/3 unit)
   The capstone experience requirement for the Minor in Materials must be satisfied by an upper level course or IS/P 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 IS/P that receives prior approval from the Program Committee for the Minor in Materials. The IS/P 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 IS/P 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 10).
   b. Physics IS/P 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 her 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).
Students interested in earning a commission as an Army Officer are required to enroll in the Advanced Course and attend the Leadership Development and Assessment Course (LDAC). LDAC is a five-week course that students are paid to attend during the summer and is the culmination of the training that the students receive while on campus. If students decide later in their academic career that they would like to pursue Army ROTC, there are alternate entry options to prepare them for the Advanced Course.

Students attending on Army ROTC Scholarships or that are enrolled in the Advanced Course receive a monthly stipend and $900 per year for books. Freshman receive $300 per month, Sophomores receive $350 per month, Juniors receive $450 per month, and Seniors receive $500 per month. Students interested in pursuing scholarships or enrolling in the Advanced course are required to meet eligibility requirements.

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<tr>
<th>MILITARY SCIENCE COURSE FLOW CHART</th>
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<td>ML I</td>
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<td>ML 1011</td>
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<td>ML 1021</td>
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<td>ML 1022</td>
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<tr>
<td><strong>BASIC COURSE</strong></td>
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<td>ML 2011</td>
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<td>ML 2021</td>
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<tr>
<td>ML 2022</td>
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<tr>
<td>LEADERSHIP TRAINING COURSE</td>
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<td>ML 2091</td>
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<td><strong>ADVANCED COURSE</strong></td>
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<td>ML 3021</td>
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<td>ML 3022</td>
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<tr>
<td>LEADERSHIP DEVELOPMENT AND ASSESSMENT COURSE</td>
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<td>ML 3023</td>
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<td>ML IV</td>
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<td>ML 4023</td>
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<td><strong>WPI DEGREE &amp; U.S. ARMY COMMISSION</strong></td>
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(1) Required for 2 year ROTC program students.
(2) Additional requirements: Professional Military Education, Five Undergraduate Courses, Leadership Laboratories, weekly, Physical Training, weekly, Weekend Field Training Exercise (2 each year), Social Events.
(3) Required attendance for all Juniors and Seniors.
PHYSICAL EDUCATION, RECREATION, AND ATHLETICS

D. L. HARMON, HEAD
ASSOCIATE PROFESSOR: P. J. Grebinar

REQUIREMENTS
Qualification in physical education shall be established by completing 1/3 unit of course work. Students are urged to complete this requirement in their first two years of residency at WPI. In addition to general PE course offerings, students may satisfy their PE requirement in the PE 1100-series courses noted below:

1. WPI approved varsity athletic team participation. Student must be registered in advance of participation.
2. Club Sports. Students must be members of a PE approved club prior to becoming eligible for physical education credit. Students must be registered in advance of participation.
3. Approved courses not offered at WPI; advance approval by the Physical Education Department is necessary. Students who wish to obtain PE credit by the above means must be enrolled in a course in the PE 1100 series.

Participation in certain ROTC programs may entitle students to a receive PE credit.

ATHLETIC PROGRAMS

THE INTERCOLLEGIATE PROGRAM
The intercollegiate athletics program offers competition in 20 varsity sports.

All full-time members of the physical education faculty and staff are involved in coaching, with assistance from other faculty members and part-time coaches from the community who have special skills in athletics.

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 athletic program forms an important point of contact with other universities and colleges in the East and is an opportunity for our students to compete against conference and independent institutions.

Varsity Sports
Baseball
Basketball (men)
Basketball (women)
Crew (men)
Crew (women)
Cross Country (men)
Cross Country (women)
Field Hockey
Football
Soccer (men)
Soccer (women)
Softball
Swimming & Diving (men)
Swimming & Diving (women)
Track (men) - Indoor/Outdoor
Track (women) - Indoor/Outdoor
Volleyball (women)
Wrestling

THE CLUB SPORTS PROGRAM
The Club Sports Program offers a variety of competitive activities for student participation. Some of the current Club Sports include:

Club Sports
Alpine Skiing
Cheerleaders
Sailing
Fencing
Scuba
Free Style Wrestling
Tennis
Golf
Ultimate Frisbee
Ice Hockey
Volleyball (men)
Lacrosse
Water Polo

Club Sports, Class II, are administered through the Department of Physical Education, Recreation, and Athletics and details regarding the activities listed above are available through the Coordinator of Club Sports in Alumni Gymnasium.

THE INTRAMURAL PROGRAM
The Intramural Program is designed as an opportunity for students to enjoy the benefits of recreation and athletic competition even though they may not have the time, talent or desire to compete on the higher intercollegiate level.

Entries are welcome not only from fraternities, sororities and other residential units but also from a variety of independent student groups and individuals, including faculty and staff. Approximately 50% of the student body participate in intramurals.

The program includes flag football, floor hockey, racquetball, volleyball, basketball, soccer, softball, and bowling. The program is ever-expanding, and activities are added as needs arise and time and facilities permit.

The program is administered by the Department of Physical Education and Athletics, and all details regarding scheduling and eligibility are available on the department website.
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.

Program Distribution Requirements for the Physics and Engineering Physics Majors

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 7), completion of a minimum of 10 units of study is required in the areas of mathematics, physics, and related fields as follows:

PHYSICS

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics (Note 1).</td>
<td>3</td>
</tr>
<tr>
<td>2. Physics (including the MQP) (Notes 2, 3).</td>
<td>5</td>
</tr>
<tr>
<td>3. Other subjects to be selected from mathematics,</td>
<td>2</td>
</tr>
<tr>
<td>science, engineering, computer science, and</td>
<td></td>
</tr>
<tr>
<td>management (Note 3).</td>
<td></td>
</tr>
</tbody>
</table>

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 and statistical physics. This core distribution requirement is satisfied by successfully completing at least one course from each of the following five sets of courses: PH 2201 or 2202 (mechanics); PH 2651 or 2601 (experimental physics); PH 3401 or 3402 (quantum mechanics); ES 3001, CH 3510, or PH 4206 (thermal and statistical physics); or other courses approved by the department Program Review Committee following petition by the student.

ENGINEERING PHYSICS
1. Same requirements as PHYSICS, with the addition that the 10 units must include 2 units of coordinated engineering and other technical/scientific activities. The 2-unit program must be formulated prior to final year of study by the student in consultation with the academic advisor, and must be certified prior to the final year by the departmental Program Review Committee.

PHYSICS AND ENGINEERING-PHYSICS PROGRAMS
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 engineering-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.

<table>
<thead>
<tr>
<th>PHYSICS COURSE</th>
<th>PHYSICS COURSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 1021 Calculus I</td>
<td>PH 1110 Mechanics</td>
</tr>
<tr>
<td>MA 1022 Calculus II</td>
<td>PH 1120 Electricity and Magnetism</td>
</tr>
<tr>
<td>MA 1023 Calculus III</td>
<td>PH 1111 Mechanics</td>
</tr>
<tr>
<td>MA 1024 Calculus IV</td>
<td>PH 1121 Electricity and Magnetism</td>
</tr>
<tr>
<td>MA 1025 Calculus III</td>
<td>PH 1130 Introduction to 20th Century Physics</td>
</tr>
<tr>
<td>MA 1024 Calculus IV</td>
<td>PH 1140 Oscillations and Waves</td>
</tr>
</tbody>
</table>
Physics and engineering-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 4201 Advanced Classical Mechanics
- PH (IS/P) Selected Readings in Physics

**Related Courses**
- ECE 2311 Continuous-Time Signal and System Analysis
- ECE 2312 Discrete-Time Signal and System Analysis
- ECE 3801 Advanced Logic Design
- ES 3011 Control Engineering I
- PH 2510 Atomic Force Microscopy
- PH 3501 Relativity
- PH 3502 Solid State Physics

**Recommended Courses**
- PH 3503 Nuclear Physics
- PH 3504 Optics
- PH (IS/P) Modern Optics
- PH 511 (Graduate) Classical Mechanics
- MA 4291 Applicable Complex Variables

2. Computational Physics.

**Recommended Courses**
- MA 3257 Numerical Methods for Linear and Non-Linear Systems
- MA 4411 Numerical Solutions of Differential Equations
- PH (IS/P) Numerical Techniques in Physics

**Related Courses**
- PH 3402 Quantum Mechanics II
- PH 3502 Solid State Physics
- MA 3457/ MA 4411 Numerical Methods for Calculus and Differential Equations
- MA 4291 Applicable Complex Variables
- 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
- ECE 2311 Continuous-Time Signal and System Analysis
- ECE 2312 Discrete-Time Signal and System Analysis
- ECE 3801 Advanced Logic Design
- ES 3011 Control Engineering I

3. Optics

**Recommended Courses**
- PH 3504 Optics
- PH 2501 Photonics
- PH 2502 Lasers

**Related Courses**
- PH 3402 Quantum Mechanics II
- PH 3502 Solid State Physics
- MA 4291 Applicable Complex Variables
- 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

4. Electromagnetism

**Recommended Courses**
- PH (IS/P) Modern Optics
- PH (IS/P) Selected Readings in Electromagnetism

**Related Courses**
- PH 3402 Quantum Mechanics II
- PH 3502 Solid State Physics
- PH 3503 Nuclear Physics
- PH 3504 Optics
- PH 533 (Graduate) Electromagnetic Theory
- PH 514/5 (Graduate) Quantum Mechanics
- MA 4291 Applicable Complex Variables
- ECE 2311 Continuous-Time Signal and System Analysis
- ECE 2312 Discrete-Time Signal and System Analysis
- ES 3011 Control Engineering I

5. Nuclear Science And Engineering

**Recommended Courses**
- Ph (ISP/P) Nuclear Physics Applications
- PH 3503 Nuclear Physics

**Related Courses**
- PH 3402 Quantum Mechanics II
- PH 3501 Relativity
- ME 4832 Corrosion and Corrosion Control
- ECE 3801 Advanced Logic Design
- ES 3011 Control Engineering I
6. Thermal Physics

Recommended Courses
ES 3001 The Statistical Development of Classical Thermodynamics
ES 3004 Fluid Mechanics
PH (IS/P) Selected Readings in Thermal Physics

Related Courses
ES 3003 Heat Transfer
ES 3011 Control Engineering I
ME 3410 Compressible Flow
PH 3502 Solid State Physics
PH 3504 Optics
ME 4429 Thermodynamic Applications and Design

7. Biophysics

Recommended Courses
ES 3001 The Statistical Development of Classical Thermodynamics
PH 4206 Statistical Physics
ME/BME 4504 Biomechanics
ME/BME 4606 Biofluids
PH (IS/P) Review of Biophysics

Related Courses
ES 3004 Fluid Mechanics
CH 4110 Biochemistry I
CH 4120 Biochemistry II
CH 4160 Membrane Biophysics
BME 2504 Foundations in Biomechanics
BME 3504 Experimental Biomechanics
BB 2550 Cell Biology

PHYSICS MINOR

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 IS/P 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
   IS/P 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 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 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 Engineering Physics do not qualify for a Minor in Physics.

PRE-LAW PROGRAMS

ADVISORS: G. HEATON, 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 72. 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.
PRE-MBA PROGRAM
(DUAL DEGREE)

ADVISOR: N. WILKINSON

FIVE-YEAR DUAL DEGREE BACHELOR/MBA PROGRAM

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 Department of Management offers the opportunity for obtaining dual degrees (i.e., the Bachelor degree in engineering or science and the Master of Business Administration, MBA). The dual-degree program can be completed within five years, however, the program is demanding, and curriculum planning with the student’s advisor and the Department of Management should start by the beginning of the student’s third year at WPI at the very latest.

Only registered WPI undergraduates majoring in an engineering (excluding Management Engineering) or science area may enter the Dual-Degree Bachelor/MBA Program. A separate and complete application to the MBA program must be submitted. Admission to the Dual-Degree Bachelor/MBA Program is determined by the faculty of the Department of Management. The student should begin the curriculum planning process as early as possible in his/her undergraduate program, but no later than the beginning of the third year, to ensure that all of the required undergraduate courses are completed within the student’s four years of undergraduate study. It is recommended that the MBA application be submitted during the student’s Third Year of undergraduate study. A student in the Dual-Degree Bachelor/MBA Program continues to be registered as an undergraduate until the bachelor’s degree is awarded.

Students wishing to do a combined Bachelor/MBA must complete the following courses while an undergraduate:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>BUS 1010</td>
<td>Leadership Practice</td>
</tr>
<tr>
<td>BUS 2060</td>
<td>Financial Statements for Decision Making</td>
</tr>
<tr>
<td>BUS 2070</td>
<td>Risk Analysis for Decision Making</td>
</tr>
<tr>
<td>BUS 3010</td>
<td>Creating Value through Innovation</td>
</tr>
<tr>
<td>BUS 3020</td>
<td>Achieving Effective Operations</td>
</tr>
<tr>
<td>BUS 4030</td>
<td>Achieving Strategic Effectiveness</td>
</tr>
<tr>
<td>MA 2611</td>
<td>Applied Statistics I</td>
</tr>
<tr>
<td>MA 2612</td>
<td>Applied Statistics II</td>
</tr>
<tr>
<td>ECON 1110</td>
<td>Introductory Microeconomics</td>
</tr>
<tr>
<td>ECON 1120</td>
<td>Introductory Macroeconomics</td>
</tr>
</tbody>
</table>

To obtain a bachelor’s degree via the Dual-Degree Bachelor/MBA Program, the student must satisfy all requirements for the bachelor’s degree, including distribution and project requirements.

To obtain an MBA via the Dual-Degree Bachelor/MBA Program, the student must satisfy all MBA degree requirements. In addition to the prerequisite undergraduate courses listed above, the student must complete the following graduate courses:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBC 511</td>
<td>Interpersonal and Leadership Skills for Technological Managers</td>
</tr>
<tr>
<td>MKT 512</td>
<td>Creating and Implementing Strategy for Technological Organizations</td>
</tr>
<tr>
<td>OIE 513</td>
<td>Creating Processes in Technological Organizations</td>
</tr>
<tr>
<td>ACC 514</td>
<td>Business Analysis for Technological Managers</td>
</tr>
<tr>
<td>BUS 515</td>
<td>Legal and Ethical Context of Technological Organizations</td>
</tr>
<tr>
<td>BUS 516</td>
<td>Graduate Qualifying Project (GQP)</td>
</tr>
<tr>
<td>12 Elective Graduate Credits</td>
<td></td>
</tr>
</tbody>
</table>

A student in the Dual-Degree Bachelor/MBA Program may, with prior approval, apply the equivalent of a maximum of 12 graduate credits from the same courses toward both the bachelor’s and MBA degrees. Students in the Dual-Degree Bachelor/MBA Program may not take graduate-level management courses prior to their Fourth Year of undergraduate study, and then only provided the corresponding prerequisites have been satisfied.

The Department of Management may make other requirements as it deems appropriate in any individual case. These requirements take the form of a written agreement between the student and the Department of Management, and must be filed with the registrar before the student may be matriculated in the Dual-Degree Bachelor/MBA Program.

The Dual-Degree Bachelor/MBA Program is a full-time program of study. Once admitted to the Dual-Degree Bachelor/MBA Program, a student must register every fall and spring semester until the MBA is completed. A student in the Dual-Degree Bachelor/MBA Program who has no registered activities during a given fall or spring semester is automatically terminated from the Dual-Degree Bachelor/MBA Program, and may only be re-admitted to the Dual-Degree Bachelor/MBA Program by the Department of Management’s Graduate Policy and Curriculum Committee and the Committee for Graduate Studies and Research via petition showing extenuating circumstances. Termination from the Dual-Degree Bachelor/MBA Program does not affect a student’s ability to continue toward the bachelor’s degree.

PRE-MEDICAL, PRE-DENTAL AND PRE-VETERINARY PROGRAMS

ADVISOR: J. RULFS

Students at WPI who wish to pursue careers in the medical professions should, in consultation with their academic advisors, plan their academic programs to include courses in biology, general and organic chemistry, and physics including laboratory experiences. Entry into medical or other health professions schools may be accomplished through any major program of study offered at WPI, although students majoring in some programs may have to use all of their electives to fulfill the required courses for medical school admission or may have to take some courses during summer sessions. It is important for students to work closely with their academic advisors as well as the pre-health advisor at WPI, to formulate an academic plan of study that will include the courses required for health professions schools. While each school may have specific and individual admissions requirements, typically these will include:

- General chemistry* 3 courses
- Organic chemistry* 3 courses
- Biology* 3 courses
- Physics* 3 courses
- Calculus 2 courses
- English composition** 2 courses

* These courses must include laboratory components.
** Check with the pre-health advisor for the use of course and project work to fulfill this requirement.
Students should consult catalogs of the individual health professions schools for specific requirements.

The WPI projects system offers a tremendous advantage to pre-health professions students. Medical, dental and veterinary schools value teamwork, as well as cross cultural, research, and medically related experience, all of which can be demonstrated through project work. Opportunities for such projects can be found on campus or at one of the project center sites at the University of Massachusetts Medical Center or Tufts University School of Veterinary Medicine or through WPI’s global projects program. These projects provide students with valuable and unique experiences that can strengthen their commitment to a health profession and their application for admission to health professions schools.

Because students will leave 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 or alumni applying to health professions school should plan to meet with the pre-health advisor to discuss the application process as well as to plan for a letter of recommendation from the pre-health office to support their application. These meetings should happen no later than the spring of the junior year or as soon as the decision is made to pursue admission to a health profession school.

PROJECT-BASED LEARNING COMMUNITY OPTION (PLC)

See page 181 for detailed description.

ROBOTICS ENGINEERING

DIRECTOR: M. A. GENNERT
ASSOCIATE DIRECTORS: F. J. LOOF, G. TRYGGVASON

ASSOCIATED FACULTY: H. K. Ault (ME), D. C. Brown (CS), S. H. Chernova, M. J. Ciarraldi (CS), D. Cyganski (ECE), M. A. Demetriou (ME), R. J. Duckworth (ECE), A. E. Emanuel (ECE), G. Fischer (ME), M. S. Fofana (ME), C. Furlong-Vazquez (ME), M. A. Gennert (CS), A. H. Hoffman (ME), X. Huang (ECE), I. Hussein (ME), S. Jarvis (ECE), R. W. Lindeman (CS), F. J. Loof (ECE), W. R. Michalson (ECE), R. L. Norton (ME), T. Padir (ECE), G. F. Pollice (CS), C. Rich (CS), Y. Rong (ME), L. E. Schachterle (Provost’s Office), K. A. Stafford (ME), G. Tryggvason (ME), J. Van de Ven (ME)

MISSION STATEMENT

Robotics—the combination of sensing, computation and actuation in the real world—is on the verge of rapid growth, driven by both supply and demand. The supply side is driven by decreasing cost and increasing availability of sensors, computing devices, and actuators. The demand side is driven by national needs for defense and security, elder care, automation of household tasks, customized manufacturing, and interactive entertainment. Engineers working in the robotics industry are mostly trained in one of Computer Engineering, Computer Science, Electrical Engineering, Mechanical Engineering, and Software Engineering. No single discipline provides the breadth demanded by robotics in the future.

PROGRAM EDUCATIONAL OBJECTIVES

The Robotics Engineering Program strives to educate men and women to

• Have a basic understanding of the fundamentals of Computer Science, Electrical and Computer Engineering, Mechanical Engineering, and Systems Engineering,
• Apply these abstract concepts and practical skills to design and construct robots and robotic systems for diverse applications,
• Have the imagination to see how robotics can be used to improve society and the entrepreneurial background and spirit to make their ideas become reality,
• Demonstrate the ethical behavior and standards expected of responsible professionals functioning in a diverse society.

PROGRAM OUTCOMES

Graduating students will have

• an ability to apply broad knowledge of mathematics, science, and engineering,
• an ability to design and conduct experiments, as well as to analyze and interpret data,
• an ability to design a robotic system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability,
• an ability to function on multi-disciplinary teams,
• an ability to identify, formulate, and solve engineering problems,
• an understanding of professional and ethical responsibility,
• an ability to communicate effectively,
• the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context,
• a recognition of the need for, and an ability to engage in lifelong learning,
• a knowledge of contemporary issues, and
• an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Program Distribution Requirements for the Robotics Engineering Major

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics (Note 1)</td>
<td>7/3</td>
</tr>
<tr>
<td>2. Basic Science (Note 2)</td>
<td>4/3</td>
</tr>
<tr>
<td>3. Entrepreneurship</td>
<td>1/3</td>
</tr>
<tr>
<td>4. Engineering Science and Design, including the MQP (Notes 3, 4, 5, 6, 7, 8, 9)</td>
<td>6 *</td>
</tr>
</tbody>
</table>

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 5/3 units in Robotics Engineering.
4. Must include at least 1 unit in Computer Science, including Object-Oriented Programming and Software Engineering.
5. Must include at least 2/3 units in Electrical and Computer Engineering, including Embedded Systems.
6. Must include at least 1/3 unit in Statics and 1/3 unit in Controls.
7. Must include at least 1/3 unit of Social Implications of Technology (CS 3043, GOV 2302, GOV/ID 2314, IMGD 2000, STS 2208).
8. Must include at least 1 unit from a list of Robotics Electives, of which at least 1/3 unit must be in Advanced Systems (CS 4341, ECE 3308, ME 3510).
9. The MQP must be a Capstone Design Experience in Robotics Engineering.
* 6 units if GOV 2302, GOV/ID 2314, or STS 2208 are double-counted as meeting the Social Science Requirement and Engineering Science and Design Requirement.

OTHER ROBOTICS PROGRAMS
WPI students can also pursue specializations involving Robotics in other departments. The department of Electrical and Computer and the department of Mechanical Engineering both encourage a focus on robotics, as detailed in their departmental descriptions. Both of these departments have sponsored final capstone design projects involving the application of their disciplines to robotics. Robotics activities are coordinated by Ken Stafford, Director of the Robotics Resource Center and head of the WPI FIRST competitive program. He oversees an active lab where students design various robotics devices in the lower level of Higgins Laboratories. You may contact him for information at (508) 831-6122 or stafford@wpi.edu.

SOCIAL SCIENCE AND POLICY STUDIES

J. K. DOYLE, HEAD
PROFESSORS: J. T. O'Connor, K. Saeed
ASSISTANT PROFESSOR: J. Skorinko
PROFESSOR OF PRACTICE: J. Lynes

MISSION STATEMENT
SSPS programs are concerned with the substance and the process of social and economic problem solving especially as related to technological development, the environment, and public policy. Most social and economic problems go beyond the boundaries of the traditional social science disciplines. Hence, the courses offered by the Department of Social Science and Policy Studies attempt to integrate knowledge and research techniques from multiple disciplines. Our curriculum covers economics, environmental studies, sociology, psychology, system dynamics, law and political science. The department encourages students to view social and economic problems, and the relationship of technology to society, from a variety of perspectives and to become acquainted with different methods of gathering and analyzing social data.

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 and 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 B.A. program in Environmental Studies.

Complete descriptions of the department’s major and minor requirements, and recommendations for completing the social science requirement are available on the SSPS Department web site at www.wpi.edu/Academics/Depts/SSPS.

PROGRAM OUTCOMES
Graduates of a social science major must have demonstrated through coursework and projects:
1. An ability to recognize patterns in real world data, qualitative and quantitative.
2. An ability to formulate hypotheses representing problems and understand their logic.
3. An ability to experiment with hypotheses to establish their validity.
4. An ability to carry out appropriate analyses to arrive at effective solutions to addressing the defined problems.
5. Literacy in the technical aspects of a problem in the student’s area of concentration.
6. An ability to effectively communicate the results of an analysis.
7. An ability to work in groups.

Program Distribution Requirements for the Economic Science, Psychological Science, Society Technology and Policy, and System Dynamics Majors

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:

**ECONOMIC SCIENCE**

**REQUIREMENTS**

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Economics (Note 1)</td>
<td>3</td>
</tr>
<tr>
<td>2. Economics and/or Management (Note 2)</td>
<td>2/3</td>
</tr>
<tr>
<td>3. Other Social Science</td>
<td>1</td>
</tr>
<tr>
<td>4. Modeling Techniques</td>
<td>2/3</td>
</tr>
<tr>
<td>5. Mathematics (Note 3)</td>
<td>2</td>
</tr>
<tr>
<td>6. Basic Science</td>
<td>1</td>
</tr>
<tr>
<td>7. Electives</td>
<td>2/3</td>
</tr>
<tr>
<td>8. MQP</td>
<td>1</td>
</tr>
</tbody>
</table>

**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, ACC1100. May include other relevant management courses as approved by the Departmental Program Review Committee.
3. Must include differential equations, integral calculus, and statistics.
PSYCHOLOGICAL SCIENCE

REQUIREMENTS MINIMUM UNITS
1. Psychological Science (Note 1) 3
2. Psychological Science and/or Related Courses (Note 2) 1
3. Other Social Science (Note 3) 1
4. Basic Science, Computer Science, and/or Engineering (Note 4) 5/3
5. Mathematics (Note 5) 4/3
6. Electives (Note 6) 1
7. MQP 1

NOTES:
1. Must include introductory psychology, social psychology, cognitive psychology, and research methods.
2. Related courses must be chosen from a list of psychology-related courses from other departments maintained by the Psychology Program Review Committee.
3. May include no more than two courses at the 1000-level.
4. Must include 1/3 unit of biology. Must include 1/3 unit of computer science (except CS 2022 and CS 3043).
5. Must include 2/3 units of calculus and 2/3 unit of statistics.
6. The 1 unit of electives must be coherently defined and approved by the Psychology Program Review Committee.

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 Management 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 management 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.

SYSTEM DYNAMICS

REQUIREMENTS MINIMUM UNITS
1. System Dynamics (Note 1) 5/3
2. Other Social Science (Note 2) 5/3
3. Management (Note 3) 2/3
4. Mathematics/basic sciences/engineering (Note 4) 8/3
5. Computer Science (Note 5) 2/3
6. Application Area (Note 6) 5/3
7. MQP 1

NOTES:
1. Only social science courses with a “5” in the second digit of the course number count toward the system dynamics requirement.
2. Must include microeconomics or macroeconomics, cognitive or social psychology, and public policy.
3. Must include organizational science.
4. Must include differential and integral calculus, differential equations, and numerical or statistical analysis.
5. Courses on computer programming and programming languages are recommended.
6. This requirement is satisfied by a cohesive set of work from the fields of social science, management, science, mathematics, computer science, or engineering as specified in the curriculum the guidelines for system dynamics major.

DESCRIPTIONS OF 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 economic science 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 4140 Ecological Management
   - GOV 2311 Legal Regulation of the Environment
   - GOV 2312 International Environmental Policy
   - PSY 2405 Environmental Problems and Human Cognition
   - 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 1520  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:
   - BB 4250  Ecological Simulation Modeling
   - 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 3501  Management Science II: Risk Analysis
   - 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

DOUBLE MAJOR IN SOCIAL SCIENCE AND POLICY STUDIES

Any of the department major programs outlined above may be taken as part of a double major in which the student majors in an area of science, engineering or management as well as social science. To obtain a double major, the student must satisfy all of the degree requirements of the technical discipline including an MQP and Distribution requirements. In addition, the double major in Social Science and Policy Studies requires four units of study in social science (inclusive of the normal two-course social science requirement) and the completion of a second qualifying project which combines the IQP and social science MQP into a single one-unit project. Unlike other double majors, the double major in Social Science and Policy Studies does not require three qualifying projects: two MQP’s and an IQP. However, the combined social science MQP and IQP must meet the goals of both. It must be interactive in nature involving an aspect of technology as well as in application of social science knowledge and analytical techniques. 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.

SOCIAL SCIENCE MINORS

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 five courses 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.