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AEROSPACE ENGINEERING

N.A. GATSONIS, DIRECTOR
PROFESSORS: M. Demetriou, N. A. Gatsonis
ASSOCIATE PROFESSORS: J. Blandino, D. Lados, D. Olinger, M. Richman
ASSISTANT PROFESSOR: R. Cowlagi
ASSISTANT TEACHING PROFESSOR: A. Linn

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.

STUDENT 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

1. Mathematics and Basic Sciences (Notes 1,2,3,4)
2. Engineering Science and Design (Includes MQP)

MINIMUM UNITS

NOTES:
1. Must include a minimum of 6/3 units of mathematics with topics in: differential calculus, integral calculus, vector calculus, multivariable calculus, differential equations and linear algebra.
2. Must include a minimum of 3/3 units in physics with topics in: introductory mechanics, electricity and magnetism, and intermediate mechanics.
3. Must include 1/3 units in space environments (fulfilled by PH 2550 Atmospheric and Space Environments as a Math and Basic Science course or other equivalent course with approval of the AE Undergraduate Committee)
4. Must include 1/3 unit in chemistry with topics in: molecularity or forces and bonding.
5. Must include 1/3 units in thermodynamics (fulfilled by PH 2101 Principles of Thermodynamics, CH 2300 Mechanical Thermodynamics as a Math and Basic Science course or ES 3001 Intro to Thermodynamics as a Free Elective or other equivalent course with approval of the AE Undergraduate Committee)
6. Must include 18/3 units in Engineering Science and Design, distributed as follows:

   a. 12/3 units in Aeronautical Engineering
      i. 2/3 units in Aerodynamics, with topics in: compressible fluid dynamics, subsonic and supersonic aerodynamics.
      ii. 2/3 units in Aerospace Materials, with topics in: introductory materials science, and aerospace materials.
      iii. 3/3 units in Structures, with topics in: stress analysis, aerospace structures, and structural dynamics.
      iv. 2/3 units in Propulsion, with topics in: incompressible fluid dynamics, and gas turbine propulsion.
      v. 2/3 units in Flight Mechanics, and Stability and Control, with topics in: control theory, and aircraft dynamics and control.
      vi. 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 AE 4770 Aircraft Design).

   b. 2/3 units in Astronautical Engineering
      i. 1/3 unit in Orbital Mechanics (fulfilled by AE 2713 Astronautics).
      ii. 1/3 units in Telecommunications (fulfilled by AE 4733 Guidance, Navigation and Communication).

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# AEROSPACE ENGINEERING PROGRAM CHART

## Course recommendation

### 12/3 UNITS OF GENERAL EDUCATION ACTIVITIES

<table>
<thead>
<tr>
<th>HUA</th>
<th>Social Science</th>
<th>Interactive Qualifying Project</th>
<th>Physical Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/3 Units</td>
<td>2/3 Units</td>
<td>3/3 Units</td>
<td>1/3 Unit</td>
</tr>
<tr>
<td>See WPI Requirements and Note 1</td>
<td>See WPI Requirements and Note 1</td>
<td>See WPI Requirements</td>
<td>See WPI Requirements</td>
</tr>
</tbody>
</table>

### 3/3 UNITS OF FREE ELECTIVE

<table>
<thead>
<tr>
<th>3/3 Units</th>
<th>See WPI Requirements, Note 1</th>
</tr>
</thead>
</table>

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

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

<table>
<thead>
<tr>
<th>Mathematics</th>
<th>Physics</th>
<th>Thermodynamics</th>
</tr>
</thead>
<tbody>
<tr>
<td>6/3 Units</td>
<td>3/3 Units</td>
<td>1/3 Unit</td>
</tr>
<tr>
<td>MA 1021 Calculus I&lt;br&gt;MA 1022 Calculus II&lt;br&gt;MA 1023 Calculus III&lt;br&gt;MA 1024 Calculus IV&lt;br&gt;MA 2051 Ordinary Diff Equations&lt;br&gt;MA 2071 Matrices and Linear Algebra.</td>
<td>PH 1110 or PH 1111 General Physics-Mechanics&lt;br&gt;PH 1120 or PH 1121 General Physics-Electricity &amp; Magnetism&lt;br&gt;PH 2201 Intermediate Mech. 1</td>
<td>PH 2101 Principles of Thermodynamics&lt;br&gt;or CH 3510 Chemical Thermodynamics&lt;br&gt;or ES 3001 Intro to Thermodynamics (as a Free Elective and see Note 2)</td>
</tr>
</tbody>
</table>

**Note 2:** If ES3001 is used to satisfy the Thermodynamics requirement then it counts as a Free Elective and a Math and Basic Science course must be taken to complete the 12/3 Unit requirement.

### 18/3 UNITS OF ENGINEERING SCIENCE AND DESIGN (Note 3 and Note 4)

#### 12/3 Units in AERONAUTICAL ENGINEERING

<table>
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<tr>
<th>Aerodynamics</th>
<th>Aerospace Materials</th>
<th>Structures</th>
<th>Propulsion</th>
<th>Flight Mechanics, and Stability and Control</th>
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<tr>
<td>2/3 Units</td>
<td>2/3 Units</td>
<td>3/3 Units</td>
<td>2/3 Units</td>
<td>2/3 Units</td>
<td>1/3 Unit</td>
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<table>
<thead>
<tr>
<th>12/3 Units in ASTRONAUTICAL ENGINEERING</th>
<th>12/3 Units in ASTRONAUTICAL ENGINEERING</th>
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<tbody>
<tr>
<td>Orbital Mechanics and Space Environments</td>
<td>Orbital Mechanics and Space Environments</td>
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<tr>
<td>1/3 Unit</td>
<td>1/3 Unit</td>
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<tr>
<td>OR</td>
<td>OR</td>
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<tr>
<td>AE 2713 Astronautics</td>
<td>AE 2713 Astronautics</td>
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<tr>
<td>AE 3711 Aerodynamics</td>
<td>AE 3711 Aerodynamics</td>
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<tr>
<td>AE 3703 Intro. to Control Dyn. Sys.&lt;br&gt;AE 4713 Spacecraft Dyn. &amp; Control</td>
<td>AE 3703 Intro. to Control Dyn. Sys.&lt;br&gt;AE 4713 Spacecraft Dyn. &amp; Control</td>
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<tr>
<td>AE 4733 Guidance, Navigation and Communications</td>
<td>AE 4733 Guidance, Navigation and Communications</td>
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<tr>
<td>AE 3701 Intro. to Materials&lt;br&gt;AE 2502 Stress Analysis&lt;br&gt;AE 3712 Aerospace Structures&lt;br&gt;AE 4712 Structural Dynamics</td>
<td>AE 3701 Intro. to Materials&lt;br&gt;AE 2502 Stress Analysis&lt;br&gt;AE 3712 Aerospace Structures&lt;br&gt;AE 4712 Structural Dynamics</td>
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<td>AE 3602 Incompressible Fluids&lt;br&gt;AE 3410 Compressible Fluid Dyn.&lt;br&gt;AE 4719 Rocket Propulsion</td>
<td>AE 3602 Incompressible Fluids&lt;br&gt;AE 3410 Compressible Fluid Dyn.&lt;br&gt;AE 4719 Rocket Propulsion</td>
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<tr>
<td>AE 4771 Spacecraft and Mission Design</td>
<td>AE 4771 Spacecraft and Mission Design</td>
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**Note 3:** The courses in the above chart can be replaced by other equivalent courses, with the approval of the AE Undergraduate Committee.

**Note 4:** 1/3 unit of an activity must be in Capstone Design (can be satisfied with MQP, AE 4770, or AE 4771).
1. Complete two units of work from courses with the prefix following requirements:
   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 astronautical topics (fulfilled by the MQP).

   or

   a. 12/3 units in Astronautical Engineering
      i. 1/3 unit in Orbital Mechanics, with topics in: space flight mechanics.
      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, with topics in: guidance, navigation and communication.
      iv. 4/3 units in Space Structures, with topics in: introductory material science, stress analysis, aerospace structures, and structural dynamics.
      v. 3/3 units in Rocket Propulsion, with topics in: 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 astronautical topics (fulfilled by AE 4771 Spacecraft and Mission Design).

   b. 2/3 units in Aeronautical Engineering
      i. 1/3 units in Aerodynamics (fulfilled by AE 3711 Aerodynamics).
      ii. 1/3 units in Flight Mechanics, and Stability and Control (fulfilled by AE 4723 Aircraft Dynamics and Control)

   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 astronautical topics (fulfilled by the MQP).

5. Must include a 1/3 Capstone design activity (fulfilled by AE 4770, AE 4771 or MQP).

6. Great Problem Seminar (GPS) courses can only be used to fulfill the HUA, SSPS or the Free Elective requirement.

**MAJOR QUALIFYING PROJECTS**

The Aerospace Engineering Program provides opportunities, resources and organization for Major Qualifying Projects (MQPs). The MQPs involve the design of an aerospace system, component, or process to meet a set of requirements and include the integration of aeronautical and/or astronautical engineering topics. MQPs are conducted in a dedicated lab or in one of the research laboratories of the Aerospace Engineering Program and serve as a vehicle for integration of undergraduate studies with current research activities. Some MQPs are also conducted in collaboration with industry or government research centers. All students present their MQP in a conference held at WPI on Project Presentation Day. Students are also encouraged and often supported to participate in student and professional conferences, as well as national design competitions. (http://www.me.wpi.edu/Aero/map.html)

**MINOR IN AEROSPACE ENGINEERING**

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

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

1. Complete two units of work from courses with the prefix “AE” as outlined in the table below.

2. Of the work in (1), at least 2/3 unit must be in 4000-level “AE” courses.

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<tr>
<th>2 Units in AEROSPACE ENGINEERING</th>
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<td>AE 4712</td>
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<td>AE/ME 4718</td>
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<tr>
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<table>
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<tr>
<th><strong>Major Aerospace Design Experience</strong></th>
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<td>AE 4771</td>
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Students seeking a Minor in AE should complete the Application for the Minor in AE and submit it to the AE Program Office as early in the program of study as possible. The Application for Minor in AE is available in the AE Program Office and the AE website. The Director of the AE Program will be responsible for review and approval of all Minor in AE requests. WPI policy requires that no more than one unit of course work be double counted toward other degree requirements.

**THE COMBINED BACHELOR’S/MASTERS PROGRAM**

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

**AIR FORCE AEROSPACE STUDIES**

**LT COL M. DeRosa, HEAD**

PROFESSOR: Lt Col M. DeRosa

ASSISTANT PROFESSORS: Capt. V. Bussmann, Capt. J. C. Hatosy

**MISSION**

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

**EDUCATIONAL OBJECTIVES:**

Students who successfully complete the AFROTC program will 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 three academic years remaining in college may apply for the Accelerated Program.

FOUR-YEAR PROGRAM

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

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

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

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

ACCELERATED PROGRAM

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

Students must join the Air Force ROTC program before or during the fall semester of their sophomore year. The applicant will be given a physical examination at no expense and will be required to meet all other retention standards. In addition, the candidate will interview with a selection board for entrance into the POC.

OTHER ASPECTS OF THE AFROTC PROGRAM

Leadership Laboratory:

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

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

Field Training:

The summer program is designed to develop military leadership, discipline, and 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 instruction in the following areas: expeditionary operations, aircraft and aircrew orientation, Air Force professional development orientation, marksmanship training, becoming an officer, physical fitness, and survival training. Uniforms, lodging, and meals are provided at no cost to the cadet. 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 approximately $500 for the four-week encampment.

Base Visits:

Air Force ROTC officer candidates may 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 will spend several days observing Air Force operations 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 Advanced Cyber Education, internships with the National Reconnaissance Office, combatives training, and global cultural language and immersion training may also be 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.

Drill Team:

Each officer candidate can elect to be part of the acclaimed Strike Eagles Honor Guard, a team dedicated to honoring our nation’s flag with outstanding drill and ceremonies, professionalism, leadership, dynamic fellowship, and pride in service. The team presents the colors at various events in the local community including Red Sox and Bruins games. At least once a year, members participate in regional competitions held in various cities and attended by ROTC drill teams nation-wide. Membership is voluntary after completion of a one semester, training-oriented pledge program. These cadets have the privilege of wearing the white or silver aiguillette on their service uniforms, depending on length of service.
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.

APPLIED PHYSICS

ADVISOR: G. S. Iannacchione
Example programs of study in Applied Physics are listed under the Physics Department. These programs include any area of engineering and represent the application of physics. Specialization include areas under Aerospace, Mechanical, Electrical and Computer, Chemical, Civil, and Biomedical Engineering.

ARCHITECTURAL ENGINEERING

DIRECTOR: R. PIETROFORTE
ASSOCIATED FACULTY: L. Albano (CEE), L. Cewe-Malloy (CEE), N. Dempsey (FPE), T. El-Korchi (CEE), K. Elovitz (CEE), B. Meachan (FPE), K. Notarianni (FPE), M. Puchovsky, S. Van Dessel (CEE)

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

PROGRAM EDUCATIONAL OBJECTIVES
1. To educate students in the fundamental principles of architectural engineering.
2. To help students develop the ability to use architectural engineering principles in analyzing and solving problems of practical importance to the built environment and society at large.
3. To educate students about the need for lifelong learning and professional development after graduation.
4. To educate students to become leaders in the architectural engineering profession and society, and develop the requisite professional and ethical demeanor for a successful engineering career.

PROGRAM OUTCOMES
Students graduating with a B.S. in Architectural Engineering will attain the following outcomes:
1. A working knowledge of the fundamentals of mathematics, physics and chemistry, including advanced subjects that further the learning of specific architectural engineering areas.
2. The ability to design and conduct experiments, to gather and analyze data as well as apply the results to address architectural engineering problems.
3. The ability to design a building system, component or process that meets desired needs within realistic constraints such as sustainability, economics, functionality, health and safety, and constructability.
4. Understanding of the building design process and the ability to develop engineering design solutions which include multidisciplinary aspects within architectural constraints.
5. Achieving the design level in one of the four architectural engineering areas, the application level in a second area, and the comprehension level in the remaining two areas.
6. The ability to use the techniques and engineering tools necessary for engineering practice.
7. The broad education necessary to understand the impact of engineering solutions in a global, political, environmental and social context.
8. Preparation for architectural engineering practice, including its technical, professional, and ethical components.
9. Understanding of the options for careers and further education, and the educational preparation necessary to pursue those options.
10. The recognition of the need for and an ability to engage in lifelong learning.
11. An ability to function on and collaborate within multidisciplinary teams.
12. An ability to write coherent and accurate technical reports and to make effective oral presentations.

Program Distribution Requirements for the Architectural Engineering Major

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

### 4 UNITS OF MATHEMATICS AND BASIC SCIENCE

<table>
<thead>
<tr>
<th>Subject</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mathematics</strong></td>
<td>5/3 Units</td>
</tr>
<tr>
<td>MA 1021 Calculus I</td>
<td></td>
</tr>
<tr>
<td>MA 1022 Calculus II</td>
<td></td>
</tr>
<tr>
<td>MA 1023 Calculus III</td>
<td></td>
</tr>
<tr>
<td>MA 1024 Calculus IV</td>
<td></td>
</tr>
<tr>
<td>MA 2051 Ordinary Differential Equations</td>
<td></td>
</tr>
<tr>
<td><strong>Statistics and Probability</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>MA 2611 Applied Statistics I</td>
<td></td>
</tr>
<tr>
<td>MA 2621 Probability for Applications</td>
<td></td>
</tr>
<tr>
<td><strong>Physics</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>PH 1110 or PH 1111 Mechanics</td>
<td></td>
</tr>
<tr>
<td>PH 1120 or PH 1121 Electricity and Magnetism</td>
<td></td>
</tr>
<tr>
<td><strong>Chemistry</strong></td>
<td>1/3 Units</td>
</tr>
<tr>
<td>CH 1010 or CH 1020 Chemistry I or Chemistry II</td>
<td></td>
</tr>
<tr>
<td><strong>Electives</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>CH 3510 Thermodynamics (Note 1)</td>
<td></td>
</tr>
</tbody>
</table>

### 1 UNIT OF ARCHITECTURAL ENGINEERING COMPLEMENTS

<table>
<thead>
<tr>
<th>Course</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR 2114</td>
<td>Modern Architecture in the American Era, 1750-2001 and Beyond</td>
</tr>
<tr>
<td>AREN 3001</td>
<td>Architectural Graphics and Communication</td>
</tr>
<tr>
<td>AREN 3002</td>
<td>Architectural Design</td>
</tr>
</tbody>
</table>

### 5 1/3 UNITS OF ENGINEERING SCIENCE AND DESIGN (Notes 2, 3)

<table>
<thead>
<tr>
<th>Subject</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Architectural Engineering</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>AREN 2023</td>
<td>Introduction to Architectural Engineering Systems</td>
</tr>
<tr>
<td>ES 3004</td>
<td>Fluids Mechanics</td>
</tr>
<tr>
<td><strong>Construction/Construction Management (select two)</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>CE 3020</td>
<td>Project Management</td>
</tr>
<tr>
<td>CE 3022</td>
<td>Legal Aspects of Professional Practice</td>
</tr>
<tr>
<td>CE 3025 (required)</td>
<td>Project Evaluation</td>
</tr>
<tr>
<td><strong>Building Mechanical Systems (select two)</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>AREN 3003 (required)</td>
<td>Principles of HVAC Design for Buildings</td>
</tr>
<tr>
<td>AREN 3024</td>
<td>Building Physics</td>
</tr>
<tr>
<td>AREN 3026</td>
<td>Building Envelope Design</td>
</tr>
<tr>
<td><strong>Building Structural Engineering (select three)</strong></td>
<td>3/3 Units</td>
</tr>
<tr>
<td>CE 2000</td>
<td>Analytical Mechanics I (or ES 2501)</td>
</tr>
<tr>
<td>CE 2001</td>
<td>Analytical Mechanics II (or ES 2502)</td>
</tr>
<tr>
<td>CE 3041</td>
<td>Soil Mechanics</td>
</tr>
<tr>
<td><strong>Building Electrical Systems</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>AREN 2025</td>
<td>Building Electrical Systems</td>
</tr>
<tr>
<td>AREN 3005</td>
<td>Lighting Systems</td>
</tr>
</tbody>
</table>

Students can achieve design proficiency in either the structural or mechanical area.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Focus on the Structural Area (select two)</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>CE 3006</td>
<td>Design of Steel Structures</td>
</tr>
<tr>
<td>CE 3008</td>
<td>Design of Reinforced Concrete Structures</td>
</tr>
<tr>
<td>CE 3010</td>
<td>Structural Engineering</td>
</tr>
<tr>
<td>CE 4017</td>
<td>Prestressed Concrete Design</td>
</tr>
<tr>
<td><strong>OR</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Design Focus on the Mechanical Area (select two)</strong></td>
<td>2/3 Units</td>
</tr>
<tr>
<td>AREN 3006</td>
<td>Advanced HVAC System Design</td>
</tr>
<tr>
<td>AREN 3025</td>
<td>Building Energy Simulation</td>
</tr>
<tr>
<td>ES 3005</td>
<td>Radiation Heat Transfer Applications</td>
</tr>
<tr>
<td>FPE 3070</td>
<td>Fundamentals of Fire Safety Analysis</td>
</tr>
</tbody>
</table>

**Major Qualifying Project (Note 4)** 3/3 Units

Note 1: Can be satisfied with CH 3510 as a mathematics and Basic Elective, or ES 3001, Introduction to Thermodynamics as a Free Elective, or other approved equivalent course.

Note 2: Must include 1/3 unit in Experimentation (fulfilled by AREN 3003, AREN 3025, ME 3901, CE 3026 or approved equivalent).

Note 3: The courses in the above Engineering Science and Design chart can be replaced by other approved equivalents.

Note 4: Must include the Capstone Design activity.

### 5 UNITS ADDITIONAL DEGREE REQUIREMENTS

<table>
<thead>
<tr>
<th>Subject</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humanities and Arts</td>
<td>6/3 Units</td>
</tr>
<tr>
<td>Social Sciences ‡</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 Units</td>
</tr>
<tr>
<td>Free Electives</td>
<td>3/3 Units</td>
</tr>
</tbody>
</table>

‡ Many SS courses complement topics in architectural engineering. Courses in environmental policy, regulations as well as environmental and development economics are recommended.
REQUIREMENTS

1. Mathematics and Basic Science (Note 1) 4
2. Architectural Engineering Complements (Note 2) 1
3. Engineering Science and Design (Notes 3, 4, 5) 5 1/3

NOTES:
1. Mathematics must include differential and integral calculus, differential equations, probability, and statistics. Science must include 2/3 unit in calculus-based physics (either the PH1110 or PH1111 series), 1/3 unit in chemistry, 1/3 unit in thermodynamics (can be fulfilled by CH 3510 or other approved equivalent course such as ES 3001).
2. Must include topics in architectural graphics and communication (AREN 3001), in architectural design, (AREN 3002), and architectural history. (AR 2114 or approved equivalent).
3. Must include 4 1/3 units in the four areas of Architectural Engineering, distributed as follows or with approved equivalents:
   a) 2/3 units in the general architectural engineering area (AREN 2023) and fluid mechanics (ES 3004)
   b) 2/3 units in construction/construction management including project evaluation (CE 3025), and either legal aspects of professional practice (CE 3022) or project management (CE 3020).
   c) 2/3 units in building mechanical systems including principles of HVAC design for buildings (AREN 3003) and either building envelope design (AREN 3026) or building physics (AREN 3024).
   d) 2/3 units in building electrical systems with topics in: building electrical systems (AREN 2025) and lighting systems (AREN 3005).
   e) 2/3 units in advanced courses in building mechanical systems selected from topics in advanced HVAC system design (AREN 3006), radiation heat transfer applications (ES 3005), fundamentals of fire safety analysis (FPE 3070) and building energy simulation (AREN 3025).

or
2/3 units in advanced courses in building structures selected from topics in steel design (CE 3006), concrete design (CE 3008), pre-stressed concrete design (CE 4017), and structural engineering (CE 3010).
4. Must include 1/3 unit in Experimentation (fulfilled by AREN 3003, AREN 3025, ME 3901, CE 3026 or approved equivalent).
5. Must include the Capstone Design activity through the MQP in one of the architectural engineering areas.

For more information please consult the website for this major at http://www.wpi.edu/academics/Dept/CEE/undergraduate/aren.html.

MINOR IN ARCHITECTURAL ENGINEERING

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

Successful candidates for the Minor in AREN must complete two units of work from courses with the prefix “AREN” as outlined in the table below.

2 Units in Architectural Engineering

Required courses
- AREN 2023 Introduction to Architectural Engineering Systems
- AREN 3001 Architectural Graphics and Communication
- AREN 3003 Principles of HVAC Design for Buildings

Elective courses (select three)
- AREN 2025 Building Electrical Systems
- AREN 3005 Building Lighting Systems
- AREN 3006 Advanced HVAC System Design
- AREN 3024 Building Physics
- AREN 3025 Building Energy Simulation
- AREN 3026 Building Envelope Design

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

BIOINFORMATICS AND COMPUTATIONAL BIOLOGY

DIRECTOR: E. RYDER (BB)
PROGRAM COMMITTEE: D. KORKIN (CS), C. RUIZ (CS), Z. WU (MA)

MISSION STATEMENT

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

PROGRAM OUTCOMES

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

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

**REQUIREMENTS**

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

**NOTES:**

1. Mathematics must include 3/3 unit of differential and integral calculus and statistics. The additional 2/3 unit must be chosen from linear algebra, statistics, probability, calculus, and differential equations.
2. Computer Science must include 2/3 unit of introductory programming and 2/3 unit of discrete math and algorithms.
3. Biology must include cell biology, genetics, molecular biology, and 1/3 unit BB 2000-level laboratory.
4. Chemistry must include 2/3 unit of general chemistry and 2/3 unit of organic chemistry.
5. Chosen from BCB interdisciplinary courses.
6. Chosen from CS 3043, STS 2208, or PY 2713.
7. Chosen from advanced courses in MA, CS, BB, or CH listed below. At least one unit must be within one area (MA, CS, or BB/CH). At least one unit must be at the 4000 level (may be in different areas).

**Advanced courses in MA:**

- MA 2431 Mathematical Modeling with Ordinary Differential Equations
- MA 2621 Probability for Applications
- MA 2631 Probability
- MA 2621 Probability for Applications
- MA 2631 Probability
- MA 4214 Survival Models
- MA 4473 Partial Differential Equations
- MA 4631 Probability and Mathematical Statistics I
- MA 4632 Probability and Mathematical Statistics II

**Advanced courses in CS:**

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

**Advanced courses in BB/CH:**

- Any BB 3000/4000 level course or CH 4000 level Biochemistry course. Particularly relevant BB/CH courses:
  - BB 3140 Evolution: Pattern and Process
  - BB 4550 Advanced Cell Biology
  - BB 4010 Advanced Molecular Genetics
  - BB/CH 4190 Regulation of Gene Expression
  - CH 4110 Biochemistry I
  - CH 4120 Biochemistry II
  - CH 4130 Biochemistry III

MINOR IN BIOINFORMATICS AND COMPUTATIONAL BIOLOGY (BCB)

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

**REQUIREMENTS**

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

**MA courses**

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

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

**CS courses**

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

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

**BB courses**

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

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

**BCB Interdisciplinary courses**

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

J. DUFFY, HEAD; J. RULFS, ASSOCIATE HEAD
PROFESSORS: D. S. Adams, K. Oates, E. W. Overström, P. J. Weathers
ASSOCIATE TEACHING PROFESSOR: M. Buckholt
ASSISTANT PROFESSORS: R. Gegear, J. Srinivasan, L. Vidali
ASSISTANT TEACHING PROFESSORS: N. Farny, S. Shell, J. Whitefleet-Smith
AFFILIATE FACULTY: M. Bakermans
EMERITUS PROFESSORS: R. Cheetham, T. C. Crusberg

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

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

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

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

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

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

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

Program Distribution Requirements for the Biology and Biotechnology Major

<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, BB 3101 and BB 4801 may count toward this requirement.
2. Biology and Biotechnology coursework must include 2/3 units at the 1000 level, 4/3 units at the 2000 level, and 4/3 units at the 3000/4000 level, of which at least 1/3 unit must be at the 4000 level. BB 1000, BB 1001 and BB 1002 may not count toward the major requirement. At least 2/3 unit of Biology and Biotechnology coursework must be taken from each of three major divisions of biology (below). The 2/3 unit for each division may include courses from any level (1000-4000).
3. • Chosen from among the BB 2000 and 3000 level labs and the Experimental Biochemistry labs, CH 4150 and CH 4170.
   • Must include at least 1/2 unit of work at the 2000 level.
   • Only one Experimental Biochemistry lab may be used (either 4150 OR 4170).
   • In addition, you may not count both CH 4150 and any of BB 3516, 3518 or 3519. Likewise, you may not count both CH 4170 and any of BB 3512, 3518 and 3520.
4. Chosen from the Related Courses List or additional BB 3000/4000 level courses.

THE THREE MAJOR DIVISIONS OF BIOLOGY

1. Cellular and Molecular
   BB 1035 Biotechnology
   BB 2003 Fundamentals of Microbiology
   BB 2550 Cell Biology
   BB 2920 Genetics
   BB 2950 Molecular Biology
   BB 3003 Medical Microbiology
   BB 4008 Cell Culture Theory and Applications
   BB 4010 Advanced Molecular Genetics
   BB 4065 Virology
   BB/CH 4190 Regulation of Gene Expression
   BB 4550 Advanced Cell Biology

2. Biology of the organism
   BB 1025 Human Biology
   BB 3010 Anatomy and Physiology I
   BB 3012 Anatomy and Physiology II
MINOR IN BIOLOGY

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

- **BB 3080** Neurobiology
- **BB 3120** Plant Physiology
- **BB 3620** Developmental Biology I
- **BB 3920** Immunology

3. Organisms in their environment

- **BB 1045** Introduction to Biodiversity
- **BB 2030** Plant Diversity
- **BB 2040** Principles of Ecology
- **BB 2050** Animal Behavior
- **BB 3140** Evolution: Pattern and Process
- **BB 4150** Environmental Change: Problems and Approaches

RELATED COURSES

- **BCB 4002** Biovisualization
- **BCB 4003** Biological and Biomedical Database Mining
- **BCB 4004** Statistical Methods in Genetics and Bioinformatics
- **CE 3059** Environmental Engineering
- **CH 2330** Organic Chemistry III
- **CH 3510** Chemical Thermodynamics
- **CH 4110** Biochemistry I
- **CH 4120** Biochemistry II
- **CH 4160** Membrane Biophysics
- **CHE 3301** Introduction to Biological Engineering

UNDERGRADUATE RESEARCH PROJECTS

The biology and biotechnology facilities offer an exceptional learning opportunity since research in an active laboratory group is the principal teaching tool. Tools for modern biochemistry, molecular biology, tissue culture, fermentation, ecology, microscopy and computer integration are all available to undergraduates. In conjunction with the faculty, students who wish to expand their educational opportunities pursue many off-campus projects each year. Investigations may take place at institutions that have traditionally worked with WPI, such as the University of Massachusetts Medical School and Tufts Cummings School of Veterinary Medicine. The department also has established links with several companies that provide opportunities for project work and summer employment in applied biology and biotechnology.

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

BB 1000, BB 1001, BB 1002 cannot be used to fulfill this requirement.

4000-level BB course 1/3
3000/4000-level BB course 1/3
BB laboratory courses (two 1/6 unit modules; note 2) 1/3
2000-level BB courses (note 1) 2/3
1000-level BB course 1/3

**NOTE**
1. At least one of the BB laboratory courses must be at the 2000-level.
2. BB 1000, BB 1001, BB 1002 cannot be used to fulfill this requirement.
2. An ability to design and conduct experiments, as well as to make measurements on, analyze and interpret data from living and non-living systems.

3. 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 while incorporating appropriate engineering standards.

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, economic, environmental 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>6/3</td>
</tr>
<tr>
<td>2. Basic Science (See Note 2)</td>
<td>6/3</td>
</tr>
<tr>
<td>3. Supplemental Science (See Note 3)</td>
<td>1/3</td>
</tr>
<tr>
<td>4. Computer Science (Note 4)</td>
<td>1/3</td>
</tr>
<tr>
<td>5. Biomedical Engineering and Engineering (See Note 5)</td>
<td>14/3</td>
</tr>
<tr>
<td>6. MQP (See Note 6)</td>
<td>3/3</td>
</tr>
</tbody>
</table>

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

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

BIOMEDICAL ENGINEERING SPECIALIZATIONS

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

BIOMECHANICS

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

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

Biomechanics research has improved our understanding of:

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

### 13/3 UNITS

<table>
<thead>
<tr>
<th>BASIC SCIENCE AND MATHEMATICS</th>
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<tbody>
<tr>
<td>Mathematics (MA): 6/3 units, including differential equations and statistics</td>
<td>HUMANITIES</td>
</tr>
<tr>
<td>Biology (BB): 2/3 units</td>
<td>See undergraduate catalog</td>
</tr>
<tr>
<td>Physics (PH): 2/3 units</td>
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</tr>
<tr>
<td>Chemistry (CH): 2/3 units</td>
<td></td>
</tr>
<tr>
<td>Supplemental Science: 1/3 unit</td>
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### 1/3 UNIT

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1/3 unit Computer Programming/Logic</td>
<td>SOCIAL SCIENCE</td>
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### 9/3 UNITS

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<tr>
<td>• Biomechanics</td>
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<tr>
<td>• Biomaterials</td>
<td></td>
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<tr>
<td>• Bioinstrumentation</td>
<td></td>
</tr>
<tr>
<td>• BME Measurement and Analysis</td>
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</tr>
<tr>
<td>1/3 unit Design</td>
<td></td>
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<tr>
<td>1/3 unit BME elective</td>
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</tbody>
</table>

| 1/3 unit engineering with living systems laboratory†                                       | MQP    |
|                                                                                              |        |
| 2/3 units BME laboratories at ≥ 3000-level (4–1/6 unit labs)                                |        |

For Depth in BME

Notes about 9/3 units:

- 1000-level courses do not satisfy requirement
- 1/3 unit at ≥ 4000-level
- 1/3 unit at 4000-level

### 5/3 UNITS

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<thead>
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<td>Engineering: 1 unit at ≥ 2000-level</td>
<td>PHYSICAL EDUCATION</td>
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<tr>
<td>Engineering: 2/3 units at ≥ 3000-level</td>
<td></td>
</tr>
</tbody>
</table>

|                                                                                              |        |
|                                                                                              | See undergraduate catalog |

### Course selections that meet the requirements for BME core knowledge

<table>
<thead>
<tr>
<th>Biomechanics/ Biofluids</th>
<th>Biomaterials/Tissue Engineering</th>
<th>Bioinstrumentation/ Biosensors</th>
<th>Measurement and Data Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>BME 2511</td>
<td>BME 2811</td>
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<td>BME 2211</td>
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<td>BME 4701</td>
<td>BME 4011 (Cat II)</td>
<td>ME 3901</td>
</tr>
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<td>BME 4814</td>
<td>BME 4201 (Cat II)</td>
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</tr>
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<td>BME 4606 (Cat II)</td>
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<td>BME 4023 (Cat I)</td>
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BIOMEDICAL INSTRUMENTATION, BIOSIGNALS AND IMAGE PROCESSING

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

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

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

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

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

Examples of biomedical imaging and image processing include:
- X-ray imaging and computer-aided tomography (CAT).
- Visible light and optical imaging.
- Near-infrared imaging.
- Magnetic resonance imaging (MRI).
- Ultrasound imaging.
- Nuclear medicine imaging.
- Luminescence-based imaging.

BIOMATERIALS AND TISSUE ENGINEERING

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

- Biomaterials Design – Identify the physiological and engineering criteria that an implantable biomaterial must meet. Select the proper chemical composition to insure that the biomaterial imparts the desired mechanical properties and evokes the appropriate tissue response for the specified application.
• Mechanics of Biomaterials – Characterize the magnitude and nature of the mechanical properties of biomaterials. Predict and measure how the physical/structural properties of a biomaterial determine its mechanical properties.

• Biomaterials-Tissue Interactions – Examine the molecular, cellular and tissue responses to implanted medical devices. Design biomaterials with properties that induce the desired wound healing and tissue remodeling responses from the body.

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

• Design and manufacture of replacements parts for damaged or diseased tissues and organs (e.g., artificial hip joints, kidney dialysis machines)
• Improved wound healing (e.g., sutures, wound dressings)
• Enhanced performance of medical devices (e.g., contact lenses, pacemakers)
• Correct functional abnormalities (e.g., spinal rods)
• Correct cosmetic problems (e.g., reconstructive 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)

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.
MANAGEMENT (MG)

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>
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</tr>
</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 School of Business 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 4200, FIN 2250, FIN 2260
   ENTREPRENEURSHIP: ETR 3635, ETR 3910, ETR 3920, ETR 4930
   MARKETING: MKT 3640, MKT 3651
   ORGANIZATIONAL BEHAVIOR: BUS 4300, OBC 3354, OBC 4366
   ECONOMICS: ECON 1130, ECON 2110, ECON 2117, ECON 2120, ECON 2125, ECON 2135
   LAW: GOV 1310, 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 School of Business Undergraduate Policy and Curriculum Committee.
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
6. A minimum of 1/3 unit of Computer Science focused on programming. CS 1101, CS 1102, or CS 1004 is recommended. (CS 2022 and CS 3043 are not accepted.)

MANAGEMENT ENGINEERING (MGE)

EDUCATIONAL OBJECTIVES
Objectives of the Management Engineering Major are:

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

Program Distribution Requirements for the Management Engineering Major

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<td>7. MGE MQP</td>
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NOTES:
1. Courses may not be counted more than once in meeting these distribution requirements. The total number of units taken in the School of Business may not exceed 50% of the total number of units earned for the degree.
3. Mathematics must include 1/3 unit of Computer Science focused on programming.
4. A minimum of 1/3 unit of Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
6. A minimum of 1/3 unit of Computer Science focused on programming. CS 1101, CS 1102, or CS 1004 is recommended. (CS 2022 and CS 3043 are not accepted.)
BUSINESS FOUNDATION CHART

Freshman and Sophomore Courses

- BUS 1010 Leadership Practice
- BUS 1020 Global Environment of Business Decisions
- BUS 2060 Financial Statements for Decision Making
- BUS 2020 Legal Environment of Business Decisions
- BUS 2070 Risk Analysis for Decision Making

ECON 1110 and ECON 1120

I. Business Context and Mindsets Cluster

II. Business Managerial Tools Cluster

- Humanities & Arts (6 courses)
- BUS 2060 Financial Statements for Decision Making
- BUS 2070 Risk Analysis for Decision Making
- BUS 2080 Data Analysis for Decision Making

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

I. Business Context and Mindsets Cluster

II. Business Managerial Tools Cluster

- PE (4 courses)

III. Business Execution Cluster

- Free Electives (5 courses)
- MAJOR (6 courses)
- Breadth Electives (3 courses)

STEM Courses (2 Calc, 2 Stat, 2 Sci, 1 CS)
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:

### Biomedical Engineering Concentration – 2 units

<table>
<thead>
<tr>
<th>Complete at least one course, but no more than two, from among:</th>
<th>and</th>
<th>Select at least four courses, but no more than five, from among:</th>
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</thead>
<tbody>
<tr>
<td>ETR 3910</td>
<td>BME 1001</td>
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<tr>
<td>ETR 3920</td>
<td>BME 2210</td>
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</tr>
</tbody>
</table>

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

### Chemistry Concentration – 2 units

<table>
<thead>
<tr>
<th>Complete at least one course, but no more than two, from among:</th>
<th>and</th>
<th>Select at least four courses, but no more than five, from among:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETR 3910</td>
<td>CH1030</td>
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<td>CH2640</td>
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<tr>
<td>OBC 3354</td>
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<tr>
<td>OBC 4366</td>
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</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Complete at least one course, but no more than two, from among:</th>
<th>and</th>
<th>Select at least four courses, but no more than five, from among:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETR 3910</td>
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</tr>
<tr>
<td>OBC 4366</td>
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</tr>
</tbody>
</table>

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

### Electrical and Computer Engineering Concentration – 2 units

<table>
<thead>
<tr>
<th>Complete at least one course, but no more than two, from among:</th>
<th>and</th>
<th>Select at least four courses, but no more than five, from among:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETR 3910</td>
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<tr>
<td>OBC 4366</td>
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</tbody>
</table>

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

### Manufacturing Engineering Concentration – 2 units

<table>
<thead>
<tr>
<th>Complete at least one course, but no more than two, from among:</th>
<th>and</th>
<th>Select at least four courses, but no more than five, from among:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETR 3910</td>
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<tr>
<td>OBC 4366</td>
<td>OBC 4366</td>
<td></td>
</tr>
</tbody>
</table>

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 School of Business Undergraduate Policy & Curriculum Committee.

### Mechanical Engineering Concentration – 2 units

<table>
<thead>
<tr>
<th>Complete at least one course, but no more than two, from among:</th>
<th>and</th>
<th>Select at least four courses, but no more than five, from among:</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETR 3910</td>
<td>OBC 3354</td>
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<tr>
<td>ETR 3920</td>
<td>OIE 3410</td>
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<tr>
<td>ETR 4930</td>
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</tr>
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<tr>
<td>OBC 4366</td>
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</tbody>
</table>

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

### Operations Management Concentration – 2 units

The MQP must have an Operations Management focus.

5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.

6. A minimum of 1/3 unit of Computer Science focused on programming, CS 1101, CS 1102, or CS 1004 is recommended. (CS 2022 and CS 3043 are not accepted.)

### MANAGEMENT INFORMATION SYSTEMS (MIS)

#### EDUCATIONAL OBJECTIVES

The objectives of the Management Information Systems Major are:

- To prepare students for positions involving the design and deployment of business applications using a wide variety of advanced information technologies, especially in high technology business, consulting, and service firms, in either start-up or established environments, and to prepare students for rapid advancement to project management and other management positions.
• To provide the knowledge and skills consistent with the professionally accepted IS curriculum guidelines. Specifically, this includes providing knowledge and skills related to:
  – business application development tools;
  – database, web-based and 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>
<th>MINIMUM UNITS</th>
</tr>
</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>
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<tr>
<td>4. Management Information Systems 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. 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 School of Business 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 3270, MIS 3270, MIS 4720, and CS 2202 or CS 2301.
   Complete two of the following courses: MIS 4741, MIS 4781, CS 2102, CS 2301 or CS 2303, CS 3041.
   Complete a MQP in MIS.
5. Breadth Electives must include at least 1/3 unit from among the 3000- and 4000-level courses in the School. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Social Science, or courses with any of the following prefixes: ACC, BUS, ETR, FIN, MIS, MKT, OBC, or OIE.
6. A minimum of 1/3 unit of Computer Science focused on programming, CS 1101, CS 1102, or CS 1004 is recommended. (CS 2022 and CS 3043 are not accepted.)

INDUSTRIAL ENGINEERING

PROGRAM MISSION
The mission of the Industrial Engineering (IE) Program at WPI is to prepare undergraduate students for professional engineering practice, providing the foundation for careers of leadership in challenging global and technological environments. We strive to accomplish this through:
• An innovative, project-based curriculum
• An emphasis on industrial engineering skills with system applications
• A flexible curriculum responsive to student interests and changes in the competitive environment
• An environment that encourages faculty/student interaction
• A culture that encourages the active involvement of students in their learning

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

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

Communication Skills. Graduates should endeavor to improve their communication skills and be able to demonstrate the effective application of various communication tools, approaches and methodologies to achieve their desired outcomes.

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

STUDENT OUTCOMES
a. Specifically, graduating students should demonstrate that they attain the following:

b. an ability to apply knowledge of mathematics, science, and engineering
c. an ability to design and conduct experiments, as well as to analyze and interpret data
d. 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
e. an ability to function on multidisciplinary teams
f. an ability to identify, formulate, and solve engineering problems
g. an understanding of professional and ethical responsibility
h. an ability to communicate effectively
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 lifelong learning

k. 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 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

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

NOTES:

1. Mathematics and Basic Science:
   a. Mathematics must include differential and integral calculus, ordinary differential equations, and 2/3 units in probability and statistics.
   b. 3/3 units of Basic Science in chemistry and physics.
   c. 2/3 units of Math/Science Electives

2. Industrial Engineering Topics must include courses in the following three topic areas:
   a. The IE Core consists of 9/3 units: BUS 1010 (Leadership Practice), BUS 2080 (Data Analysis for Decision Making) or MA 2210* (Mathematical Methods in Decision Making), BUS 3020 (Achieving Effective Operations), CS 220X (Application Building with Object-oriented Concepts), OIE 2850 (Engineering Economics), OIE 3410 (Materials Management in Supply Chains), OIE 3420 (Quality Planning, Design and Control), OIE 3460 (Simulation Modeling and Analysis), and OIE 3510 (Stochastic Models).
   *IE majors cannot receive credit for both BUS 2080 and MA 2210.
   b. IE Electives (3/3 units): Any 3000- or 4000-level Operations Research courses in MA, MIS 3720, 4720, OIE 3405, 4410, 4420, 4460.

MINOR IN BUSINESS

Everyone needs management skills. If engineers, scientists, and others hope to advance in their careers, they must learn how to lead projects and manage groups. The Business Minor offers students (other than 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 learn some of the theory and practice of managing in organizations with material on management concepts and practices commonly encountered in the business world. This program will help students make a transition to the business world and will provide basic skills for operating effectively in business organizations.

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

1. Select any five from the following:
   ECON 1110 OR ECON 1120
   BUS 1010 Leadership Practice
   BUS 1020 Global Environment of Business Decisions
   BUS 2020 The Legal Environment of Business Decisions
   BUS 2060 Financial Statements for Decision Making
   BUS 2070 Risk Analysis for Decision Making
   BUS 2080 Data Analysis for Decision Making
   BUS 3010 Creating Value through Innovation
   BUS 3020 Achieving Effective Operations

2. Select one of the following two courses:
   BUS 4030 Achieving Strategic Effectiveness
   ETR 4930 Growing and Managing New Ventures

   This minor is not available to students in any Management, Management Engineering, or Management Information Systems major at WPI.

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

MINOR IN ENTREPRENEURSHIP

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

Related opportunities include competitions for the following: The Robert H. Grant Invention Awards, the Henry Strage Innovation Award, and the Kalenian Award. Through the Collaborative for Entrepreneurship and Innovation, WPI sponsors the Innovation and Entrepreneurship Club, participates in Global Entrepreneurship Week, and promotes and supports the MassChallenge Competition.

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

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

1. Complete the following course:
   BUS 2060 Financial Statements for Decision Making

2. Complete two (2) from the following list:
   ETR 1100 Engineering Innovation and Entrepreneurship
   ETR 3633 Entrepreneurial Selling
   ETR 3910 Recognizing and Evaluating New Venture Opportunities
   ETR 3920 Planning & Launching New Ventures

3. Complete two (2) of the following courses:
   BUS 2070 Risk Analysis for Decision Making
   BUS 3010 Creating Value through Innovation
   MKT 3640 Management of Process and Product Innovation
   GOV 2313 Intellectual Property Law

4. Required:
   ETR 4930 Growing and Managing New Ventures

For general policy on the Minor, see the description on page 11.
MINOR IN INDUSTRIAL ENGINEERING

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

The IE minor is available to students in any major at WPI except for those majoring in Industrial Engineering.

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

1. IE Tools, select at least two (2):
   - BUS 2080 Data Analysis for Decision Making or MA 2210 Mathematical Methods in Decision Making
   - OIE 2850 Engineering Economics
   - OIE 3460 Simulation Modeling and Analysis
   - OIE 3510 Stochastic Models

2. IE Knowledge, select at least two (2):
   - BUS 3020 Achieving Effective Operations
   - OIE 3405 Work Systems and Facilities Planning
   - OIE 3410 Materials Management in Supply Chain
   - OIE 3420 Quality Planning, Design, and Control
   - OIE 4410 Case Studies in Industrial Engineering
   - OIE 4460 Global Planning and Logistics

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

MINOR IN MANAGEMENT INFORMATION SYSTEMS

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

To complete the Management Information Systems Minor, a student must complete two units of work as outlined below.

1. A total of three (3) courses in Business Foundation and Programming Skills, with at least one (1) from each group:
   A. Business Foundation:
      - BUS 1010 Leadership Practice
      - BUS 1020 Global Environment of Business Decisions
      - BUS 2020 The Legal Environment of Business Decisions
      - BUS 2060 Financial Statements for Decision Making
      - BUS 2070 Risk Analysis for Decision Making
      - BUS 2080 Data Analysis for Decision Making
      - BUS 3010 Creating Value through Innovation
      - BUS 3020 Achieving Effective Operations
      - BUS 4030 Achieving Strategic Effectiveness
   B. Programming Skills:
      - CS 1101 Introduction to Program Design or CS 1102 Accelerated Introduction to Program Design, or CS 1004 Introduction to Programming for Non-Majors
      - CS 2102 Object Oriented Design Concepts
      - CS 220X Application Building with Object-Oriented Concepts
      - CS 2301 Systems Programming for Non-Majors or CS 2303 Systems Programming Concepts

2. Two (2) courses from the group of courses:
   - MIS 3720 Management of Data
   - MIS 3740 Organizational Application of Telecommunications
   - MIS 4741 User Experience and Design
   - MIS 4781 Information Systems and Technology Policy and Strategy

3. Required:
   - MIS 4720 Systems Analysis and Design

Students majoring in MIS may not take the MIS Minor.

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

MINOR IN SOCIAL ENTREPRENEURSHIP

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

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

1. Required:
   - BUS 1010 Leadership Practice

2. Select two (2):
   - ETR 3633 Entrepreneurial Selling
   - ETR 3910 Recognizing and Evaluating New Venture Opportunities
   - ETR 3920 Planning and Launching New Ventures
   - ETR 4930 Growing and Managing New Ventures

3. Select two (2):
   - BUS 1020 Global Environment of Business Decisions
   - BUS 2020 Legal Environment of Business Decisions
   - ENV 1100 Introduction to Environmental Studies
   - ENV 2400 Environmental Problems and Human Behavior
   - ENV 2600 Environmental Problems in the Developing World
   - ENV 4400 Senior Seminar in Environmental Studies
   - OBC 3354 Organizational Behavior and Change
   - PSY 1402 Social Psychology
   - PSY 2406 Cross-Cultural Psychology
   - SOC 1202 Introduction to Sociology and Cultural Diversity
4. Required:
   - OBC 4366 Leadership, Ethics, and Social Entrepreneurship
   (or a suitable ISP)

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

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

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**CHEMICAL ENGINEERING**

**D. DIBIASIO, HEAD**


ASSOCIATE PROFESSORS: W. M. Clark, D. DiBiasio, H. Zhou

ASSISTANT PROFESSORS: N. A. Deskins, A. M. Peterson, M. T. Timko

PROFESSOR OF PRACTICE: S. J. Kmiotek

RESEARCH ASSOCIATE PROFESSOR: I. Mardilovich

RESEARCH ASSISTANT PROFESSORS: G. Tompsett, B. Castro-Dominguez

ADJUNCT ASSISTANT PROFESSORS: H. W. Nowick, T. Starr

ASSOCIATED FACULTY: J. Bergendahl (CEE), M. Emmert (CBC), J. Liong (ME), K. Notarianni (FPE), A. Rangwalla (FPE), Y. Wang (ME)

EMERITUS FACULTY: W. R. Moser, A. H. Weiss

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**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 and the safe design and operation of chemical processes. 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.

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**PROGRAM EDUCATIONAL OBJECTIVES**

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

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

---

**STUDENT OUTCOMES**

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

Students shall demonstrate:

(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 function on multi-disciplinary teams;
(e) an ability to identify, formulate, and solve engineering problems;
(f) an understanding of professional and ethical responsibility;
(g) an ability to communicate effectively;
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for and an ability to engage in life-long learning;
(j) a knowledge of contemporary issues; and,
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

---

**Program Distribution Requirements for the Chemical Engineering Major**

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

**REQUIREMENTS**

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

**NOTES:**

1. Must include differential and integral calculus and differential equations.
2. Must include 3 courses in chemistry, 2 courses in physics and 1 course in biology or biochemistry.
3. Must include 1 unit of MQP, 1/3 unit of capstone design experience (e.g. CHE 4404), and at least 1/3 unit of engineering study outside the major. Courses used to satisfy this requirement must be at the 2000-level or above, with the exception of CHE 1011.
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 2550 Cell Biology
BB 4008 Cell Culture Theory and Applications
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

No more than one 1000-level course may be counted. Recommended courses include:

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 2511 Introduction to Biomechanics and Biotransport
BME/ME 4504 Biomechanics
BME/ME 4606 Biofluids
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
CHE/CEE 4063 Transport and Transformations in the Environment
(at most, one of these three) {CE 3059 Environmental Engineering, CE 3070 Introduction to Urban and Environmental Planning, CE 3074 Environmental Analysis

CHEMICAL ENGINEERING WITH MATERIALS CONCENTRATION

Engineering Science and Design:
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
Biochemical Engineering
Biofilms & Biomaterials
Biofuels
Biominiaturization
Bioremediation
Biosensors
Biotechnology
Catalysis
Chemical Process Safety
Chemical Risk Assessment and Management
Diffusion
Drug Delivery
Energy
Fuel Cells

Hydrogen Technology
Inorganic Membranes
Kinetics
Mass Transfer
Materials Synthesis
Microfluidics
Molecular Modeling
Polymers and Composites
Process Dynamics, Supervision and Control
Reaction Engineering
Scientific Computing
Separation Processes
Thermodynamics
Water Purification and Remediation
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 1/3</td>
</tr>
<tr>
<td>3. Biology (Note 3).</td>
<td>1 1/3</td>
</tr>
<tr>
<td>4. 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 4 1/3 units must include one unit of organic, 1 1/3 units of biochemistry, and 1/3 unit each of physical (3000 level or higher) and inorganic chemistry (3000 level or higher).
3. These 1 1/3 units must include 1/3 unit of cell biology, 1/3 unit of genetics, and 1/3 unit of advanced work (3000 level or higher).
4. This unit must include a minimum of 2/3 units of Chemistry and Biochemistry labs, of which 1/3 unit must be either CH 4150 or CH 4170. The remaining 1/3 unit may come from BB or CBC labs. However, counting both CH 4150 and any of BB 3518, BB 3519, or BB 3516 is not allowed. Likewise, counting both CH 4170 and any of BB 3512 or BB 3518 is not allowed.
5. Any course in the natural sciences (not used to satisfy another requirement) or in computer science may be used to satisfy this requirement.

RECOMMENDATIONS FOR STUDENTS
A typical Biochemistry curriculum is given below.

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

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

<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>
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<tr>
<td></td>
<td>BB 2550</td>
<td>HU MA</td>
<td>BB 2920</td>
<td>HU MA</td>
</tr>
<tr>
<td></td>
<td>MA</td>
<td></td>
<td>MA</td>
<td></td>
</tr>
<tr>
<td>Second</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 HU</td>
<td>HU PH</td>
<td>HU PH</td>
</tr>
<tr>
<td></td>
<td>HU</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third</td>
<td>CH 4110</td>
<td>CH 4120</td>
<td>CH 4130</td>
<td>CH 4170</td>
</tr>
<tr>
<td></td>
<td>BB Lab SS</td>
<td>CH 4150 IQP</td>
<td>CH 3410 IQP</td>
<td>Elective</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IQP</td>
<td>IQP</td>
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<td></td>
</tr>
<tr>
<td>Fourth</td>
<td>Elective</td>
<td>MQP Elective</td>
<td>CH 4160</td>
<td>CH 4190</td>
</tr>
<tr>
<td></td>
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<td>Elective</td>
<td>MQP Elective</td>
<td>Elective</td>
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</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**

**MINIMUM UNITS**

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

**NOTES:**

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

RECOMMENDATIONS FOR STUDENTS

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

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

AMERICAN CHEMICAL SOCIETY APPROVAL AND CERTIFICATION

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

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

ACS-CERTIFIED DEGREE IN CHEMISTRY

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

Recommended CBC Courses for an ACS-Certified Degree in Chemistry

<table>
<thead>
<tr>
<th>Year</th>
<th>Term A</th>
<th>Term B</th>
<th>Term C</th>
<th>Term D</th>
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</thead>
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<tr>
<td>First</td>
<td>CH 1010</td>
<td>CH 1020</td>
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<td>CH 1040</td>
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<tr>
<td></td>
<td>CH 1020</td>
<td>HU MA</td>
<td>BB 2920</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Second</td>
<td>CH 2640</td>
<td>CH 2560</td>
<td>CH 2310</td>
<td>CH 2320</td>
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<tr>
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<td>(org)</td>
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<td></td>
<td>CH 3510</td>
<td>CH 3210</td>
<td>HU PH</td>
<td>HU PH</td>
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<tr>
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<td>(phys)</td>
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</tr>
<tr>
<td>Third</td>
<td>CH 3550</td>
<td>CH 3410</td>
<td>CH 3430</td>
<td>CH 3470</td>
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</tr>
<tr>
<td>Fourth</td>
<td>CH 4110</td>
<td>CH 4150</td>
<td>CH 4170</td>
<td>CH 4190</td>
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<tr>
<td></td>
<td>(bioch)</td>
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<td>Elective</td>
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<td>(org)</td>
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<td>(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
- CH 4150 Experimental Biochemistry
- CH 4170 Experimental Biochemistry II
- BB 3055 Microbial Physiology

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. 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
- Animal-Virus Biochemistry
- Photochemistry
- Photophysics
- Sensors
- Supramolecular Chemistry

**MINOR IN BIOCHEMISTRY**

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

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

1. 1/3 unit of organic chemistry selected from
   - CH 2320
   - CH 2330
   - CH 2360

2. 1/3 unit of biology focused on cellular or subcellular biology. Acceptable courses include
   - BB 2550
   - BB 2920
   - BB 3080
   - BB 3620
   - BB 3920
   - BB 4010
   - BB 4065
   - BB 4550

3. At least 3/3 unit of biochemistry selected from
   - CH 4110
   - CH 4120
   - CH 4130
   - CH 4140
   - CH 4150
   - CH 4170
   - CH 4190

Majors in chemistry may not receive a biochemistry minor.
MINOR IN CHEMISTRY

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

REQUIREMENTS

<table>
<thead>
<tr>
<th>REQUIREMENTS (Note 1)</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 level CH course</td>
<td>1/3</td>
</tr>
<tr>
<td>2000 level CH courses (Note 2)</td>
<td>2/3</td>
</tr>
<tr>
<td>3000/4000 level CH courses</td>
<td>2/3</td>
</tr>
<tr>
<td>4000 level CH courses (capstone)</td>
<td>1/3</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 Minor with Depth in Physical Chemistry**
---|---
CH 1020 Forces and Bonding | CH 1020 Forces and Bonding
CH 2310 Organic Chemistry I | CH 3510 Chemical Thermodynamics
CH 2320 Organic Chemistry II | CH 3530 Quantum Chemistry
CH 3510 Chemical Thermodynamics | CH 3550 Chemical Dynamics
CH 3410 Principles of Inorganic Chemistry | CH 3410 Principles of Inorganic Chemistry
CH 4110 Biochemistry I | 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, R. Mallick
ASSISTANT PROFESSORS: Y. Kim, N. Rahbar, A. Sakulich
INSTRUCTORS: S. LePage, L. Cewe-Malloy
TEACHING PROFESSOR: J. Hall
ASSOCIATE TEACHING PROFESSOR: S. Van Dessel
ASSISTANT TEACHING PROFESSOR: D. Rosbach
EMERITUS PROFESSORS: F. DeFalco, R. Fitzgerald, J. C. O’Shaughnessy

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 as part of interdisciplinary teams to analyze and solve problems and to produce creative effective and sustainable design solutions.
3. have the ability to engage in life-long learning, enhance their technical skills through graduate studies and continuing education, and gain relevant experience, in the professional practice of engineering.
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:

<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. Engineering Science and Design (including the MQP) (Note 3,4,5,6)</td>
<td>6</td>
</tr>
</tbody>
</table>

NOTES:
1. Mathematics must include differential and integral calculus, differential equations, and probability and statistics.

2. Must include at least one course in physics, two courses in chemistry, and one course in an additional science area.

3. A minimum of 4 units of work must be within the Civil Engineering area. All CE courses including the MQP ES 2503, ES 2800, and ES 3004 are acceptable within the Civil Engineering area.

4. The curriculum must include at least one engineering science course outside the major discipline area. Courses acceptable to satisfy the requirement of outside-of-discipline course are those taught in other engineering departments. The course must be 2000-level or above and cannot include ES 2501, ES 2502, ES 2503, ES 2800, and ES 3004.

5. All students are required to include an appropriate laboratory experience as part of their overall program. This experience can be met by the completion of two undergraduate CE lab courses, selected from among the following: CE 2020, CE 3024, CE 3026, CE 4054, and CE 4060. Alternatively, 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.

**CIVIL ENGINEERING PROGRAM CHART**

This chart summarizes course and scheduling recommendations.

<table>
<thead>
<tr>
<th>First Year/ Sophomore</th>
<th>MATHEMATICS AND SCIENCE (4 units minimum required)</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>HUMANITIES AND ARTS (2 units minimum required)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MQP</td>
<td>Project in areas of interest, including capstone design</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anytime</th>
<th>SOCIAL SCIENCE (2/3 units minimum required)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PHYSICAL EDUCATION (1/3 unit minimum required)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>First Year/ Sophomore</th>
<th>ENGINEERING SCIENCE AND DESIGN (6 units minimum required; 4 units minimum required in Civil Engineering)</th>
</tr>
</thead>
</table>

| Junior/ Senior | Outside of CE ES 2001, ES 3001, FCE 2010 or other 2000-level or above engineering course |

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<thead>
<tr>
<th>Civil Engineering</th>
<th>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>
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<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>
<td>CE 3025</td>
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<td>CE 3006</td>
<td>CE 3044</td>
<td>CE 3060</td>
<td>CE 3074</td>
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<td>CE 3008</td>
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<td>CE 3061</td>
<td>CE 4071</td>
<td>CE 3052</td>
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<td>CE 4007</td>
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<td>CE 3062</td>
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<td>CE 4017</td>
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<td>CE 4061</td>
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<td>Labs</td>
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<td>CE 4060</td>
<td>CE 4054</td>
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<tr>
<td>MQP</td>
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<tr>
<td>ELECTIVES (1 unit)</td>
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</table>
## 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 69 can aid students in developing their plan of study.

### Subareas of Civil Engineering

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

### STRUCTURAL AND GEOTECHNICAL ENGINEERING

L. Albano, T. El-Korchi, Y. Kim, R. Mallick, N. Rahbar, A. Sakulich, 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. 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.

### TRANSPORTATION ENGINEERING

T. El-Korchi, R. Mallick, M. Tao

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

### URBAN AND ENVIRONMENTAL PLANNING

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.
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 encouraged to take the FE exam during their senior year. The exam is offered year-round.

### Fundamentals of Engineering Exam

Continued studies beyond the bachelor's degree are valuable for career advancement and professional engineering licensure. The FE exam during their senior year. The exam is offered year-round.

### Combined Bachelor/Master’s Program

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

### Computer Science

#### C. E. Wills, Head

**DMKEL, ASSOCIATE HEAD**


RESEARCH PROFESSORS: J. Gutman, C. L. Sidner

VISITING ASSOCIATE PROFESSOR: G. N. Sarkozy

ADJUNCT TEACHING PROFESSOR: H. C. Lauer

INSTRUCTOR: G. F. Pollice

SENIOR INSTRUCTORS: M. J. Ciaraldi, G. Hamel

PROFESSORS EMERITUS: K. A. Lemone, S. M. Selkow

**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.
COMPUTER SCIENCE COURSE FLOW CHART

CS 1101
Introduction to Program Design
OR
CS 1102
Accelerated Intro. to Program Design

CS 2102
Object-Oriented Design Concepts
CS 2303
Systems Programming Concepts

CS 2011
Machine Organization & ASSEMBLY Language

CS 3013
Operating Systems
CS 3516
Computer Networks

CS 3012
Computer Networks
CS 4513
Distributed Computer Systems

CS 4516
Advanced Computer Networks
CS 4515
Computer Architecture

CS 4233
Object-Oriented Analysis & Design
CS 4241
Webware

CS 4401
Software Security Engineering
CS 4432
Database Systems II

CS 4402
Differential Equations
CS 4433
Database Systems III

CS 4431
Database Systems I
CS 4445
Data Mining

CS 4432
Software Engineering
CS 4434
Data Structures

Note: The chart does not specify dependencies with non-CS courses; consult the catalog.
For dependencies of non-major courses, see Computer Science course chart for Non-Majors

CS 2022
Discrete Mathematics
CS 2223
Algorithms

CS 3022
Discrete Mathematics
CS 3032
Discrete Structures

CS 3043
Social Implications of Information Processing
CS 3133
Foundations of Computer Science

CS 3431
Database Systems I
CS 3441
Artificial Intelligence

CS 3432
Database Systems II
CS 3442
Artificial Intelligence

CS 3516
Computer Networks
CS 3515
Computer Architecture

CS 4032
Numerical Methods for Linear & Non-Linear Systems
CS 4033
Numerical Methods for Calculus & Differential Equations

CS 4042
Software Engineering
CS 4043
Software Development

CS 4311
Computer Graphics
CS 4312
Computer Animation

CS 4332
Advanced Programming Languages
CS 4333
Advanced Programming Languages

CS 4512
Advanced Computer Networks
CS 4513
Distributed Computer Systems

CS 4514
Computer Architecture
CS 4515
Computer Architecture

CS 4516
Advanced Computer Networks
CS 4517
Advanced Computer Networks

CS 4532
Advanced Programming Languages
CS 4533
Advanced Programming Languages

CS 4731
Computer Graphics
CS 4732
Computer Animation
## 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.

## COMPUTER SCIENCE PROGRAM CHART

<table>
<thead>
<tr>
<th>Core Courses</th>
<th>Minimum 18/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 1101 or CS 1102, CS 2011, CS 2102, CS 2223, CS 2303, CS 3013, CS 3041, CS 3043, CS 3133, CS 3733</td>
<td></td>
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<table>
<thead>
<tr>
<th>Systems</th>
<th>Minimum 1/3</th>
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</thead>
<tbody>
<tr>
<td>CS 3013, CS 4513, CS 4515, CS 4516</td>
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<table>
<thead>
<tr>
<th>Theory and Language</th>
<th>Minimum 1/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 3133, CS 4120, CS 4123, CS 4533, CS 4536</td>
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<table>
<thead>
<tr>
<th>Design</th>
<th>Minimum 1/3</th>
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</thead>
<tbody>
<tr>
<td>CS 3041, CS 3431, CS 3733, CS 4233</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Social Implications</th>
<th>Minimum 1/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 3043, STS 2208, GOV/ID 2314</td>
<td></td>
</tr>
<tr>
<td>STS 2208, GOV/ID 2314 do not count toward the 18/3 CS units</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Advanced Level Courses</th>
<th>Minimum 5/3</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Computer Science MQP</th>
<th>Minimum 3/3</th>
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</table>

<table>
<thead>
<tr>
<th>Science</th>
<th>Minimum 5/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Mathematics</th>
<th>Minimum 7/3</th>
</tr>
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<tbody>
<tr>
<td>At most four 1000-level Mathematics courses. May include CS 2022, CS 4032 or CS 4033 if not used to satisfy the CS requirements.</td>
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</table>

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Minimum 1/3</th>
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<tbody>
<tr>
<td>MA 2611, MA 2612</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Probability</th>
<th>Minimum 1/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 2621, MA 2631</td>
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</table>
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

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

NOTES:
1. a. Only CS 1101, CS 1102 and computer science courses at the 2000-level or higher will count towards the computer science requirement. CS 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.

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.

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, the Japan Project Center, and the Wall Street Project Center.

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

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

ADVANCED PLACEMENT
Advanced placement in computer science can be earned for the A computer science exam. Credit for CS 1000 is granted for scoring a “4” or “5” on the CS exam.

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

MINOR IN COMPUTER SCIENCE
The Minor in Computer Science will consist of 2 units from Computer Science, with no more than one course at the 1000-level. The 2 units must include one of the following, each of which provides an integrating capstone experience.

- Any CS 3000-level course, except for CS 3043
- Any CS 4000-level course, except for CS 4032 and CS 4033
- Any graduate-level computer science course, except for CS 505
- 1/3 unit of another activity, for example an ISP, which is validated by the CS faculty instructor as a capstone

The Computer Science Department has an advisor for CS Minors. Students are required to consult with the CS Minor Advisor before declaring the CS Minor. Majors in Computer Science and Computers with Applications do not qualify for a Minor in Computer Science. Students should review the Operational Rules of the Minor at WPI to avoid problems with double counting CS courses.

Students should review the Operational Rules of the Minor at WPI to avoid problems with double counting CS courses. For general policy on the Minor, see the description on page 11.

ELECTRICAL AND COMPUTER ENGINEERING

Y. MASSOUD, HEAD; J. McNEILL, ASSOCIATE HEAD
ASSOCIATE PROFESSORS: D. R. Brown, R. J. Duckworth, H. Hakim, X. Huang, B. Sunar, R. F. Vaz, A. Wyglinski
ASSISTANT PROFESSORS: A. Clark, T. Eisenbarth, A. Klein, L. Lai, T. Padir
ASSISTANT TEACHING PROFESSORS: Y. Bogdanov, S. M. Jarvis, S. Virani
INSTRUCTOR: S. J. Bitar

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

PROGRAM EDUCATIONAL OBJECTIVES
The Electrical and Computer Engineering Department offers a balanced, integrated curriculum strong in both fundamentals and state-of-the-art knowledge. The curriculum embraces WPI’s philosophy of education, with a program characterized by curricular flexibility, student project work such as the Interactive Qualifying Project, and active involvement of students in their learning.
Through this approach, the Electrical and Computer Engineering Program seeks to have alumni who:

- are successful professionals based on their breadth of knowledge in the field of electrical and computer engineering, and are prepared for both immediate professional practice as well as engagement with graduate study and lifelong learning;
- are effective contributors in business and society, demonstrating the ability to communicate, work in teams, and understand the broad implications of their work;
- are prepared broadly for both their professional and personal lives, providing the basis for effective leadership and informed citizenship.

PROGRAM OUTCOMES

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

(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 function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

NOTES:

1. Mathematics and Basic Science:
   a. Must include at least 7/3 units of math (prefix MA). Mathematics must include differential and integral calculus, differential equations, and probability.
   b. Must include at least 2/3 units of physics (prefix PH).
   c. Must include at least 1/3 units of chemistry (prefix CH) or 1/3 units of biology (prefix BB).
   d. Must include an additional 2/3 units of math or basic science (prefixes MA, PH, CH, BB, or GE).

2. Engineering Science and Design (including the MQP):
   a. Must include at least 5 units at the 2000-level or higher within the Electrical and Computer Engineering area (including the MQP). All courses with prefix ECE at the 2000-level or higher and ES 3011 are applicable to these 5 units.
   b. The 5 units within the Electrical and Computer Engineering area must include at least 1 unit of courses from these approved Electrical Engineering courses: ECE 2112, ECE 2201, ECE 2305, ECE 2312, ECE 3113, ECE 3204, ECE 3308, ECE 3311, ECE 3500, ECE 3501, ECE 3503, ECE 4011, ECE 4023, ECE 4305, ECE 4703, ECE 4902, ECE 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 2029, ECE 2049, ECE 3829, ECE 3849 and ECE 4801.
   d. The 5 units within the Electrical and Computer Engineering area must include 1/3 unit of Capstone Design Experience. (This requirement is typically fulfilled by the MQP)
   e. Must include at least 1/3 unit of computer science (prefix CS), at the 2000-level or above (other than CS 2011, CS 2022, CS 3043 which cannot be applied to this requirement).
   f. Must include 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 AREN, BME, CE, CHE, CS (other than CS 2011, CS 2022, CS 3043), ECE, ES, FP, ME, or RBE.

SUBDISCIPLINES WITHIN ECE

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

Robotics
Area Consultants: Cyganski, Duckworth, Looft, Michalson, Padir
Area Courses
ECE 2029 Introduction to Digital Circuit Design
ECE 2049 Embedded Computing in Engineering Design
ECE 3849 Real-time Embedded Systems
ES 3011 Control Engineering I
Related Courses
CS 4341  Artificial Intelligence
ECE 2201  Microelectronics I
ECE 3503  Power Electronics
RBE 1001  Introduction to Robotics
RBE 2001  Unified Robotics I: Actuation
RBE 2002  Unified Robotics II: Sensing
RBE 3001  Unified Robotics III: Manipulation
RBE 3002  Unified Robotics IV: Navigation

Power Systems Engineering
Area Consultants: Emanuel, Hakim, Orr
Area Courses
ECE 3500  Introduction to Contemporary Electric Power Systems
ECE 3501  Electrical Energy Conversion
ECE 3503  Power Electronics
Related Courses
ES 3001  Introduction to Thermodynamics
ES 3011  Control Engineering I
ME 1800  Manufacturing Science Prototyping and Computer-Controlled Machining
OIE 2850  Engineering Economics

RF Circuits and Microwaves
Area Consultants: Ludwig, Makarow, Massoud
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, Lai, Makarow, Pahlavan, Wyglinski
Area Courses
ECE 2305  Introduction to Communications and Networks
ECE 2312  Discrete-Time Signal and System Analysis
ECE 3308  Introduction to Wireless Networks
ECE 3311  Principles of Communication Systems
ECE 4305  Software-Defined Radio Systems and Analysis
ECE 4703  Real-Time Digital Signal Processing
Related Courses
ES 3011  Control Engineering I
MA 2071  Matrices and Linear Algebra I
MA 2621  Probability for Applications
MA 4291  Applicable Complex Variables

Biomedical Engineering
Area Consultants: Clancy
Area Courses
ECE/BME 4011  Biomedical Signal Analysis
ECE/BME 4023  Biomedical Instrumentation Design
Related Courses
BME 4201  Biomedical Imaging
ECE 2201  Microelectronic Circuits I
ECE 2312  Discrete-Time Signal and System Analysis
ECE 3204  Microelectronic Circuits II

Analog Microelectronics
Area Consultants: Bitar, Massoud, McNeill
Area Courses
ECE 2201  Microelectronics I
ECE 3204  Microelectronics II
ECE 4902  Analog Integrated Circuit Design
ECE 4904  Semiconductor Devices
Related Course
ES 3011  Control Engineering I

Computer Engineering
Area Consultants: Clancy, Cyganski, Duckworth, Eisenbarth, Huang, Jarvis, Looft, Michalson, Sunar
Area Courses
ECE 2029  Introduction to Digital Circuit Design
ECE 2049  Embedded Computing in Engineering Design
ECE 3829  Advanced Digital System Design with FPGAs
ECE 3849  Real-time Embedded Systems
ECE 4801  Computer Organization and Design
Related Courses
ECE 2201  Microelectronics I
CS 2223  Algorithms
CS 3013  Operating Systems
CS 3733  Software Engineering
CS 4515  Computer Architecture
CS 4536  Programming Languages

OVERVIEW OF OTHER PROGRAM COMPONENTS

ENGINEERING SCIENCE AND DESIGN
Because modern engineering practice is increasingly interdisciplinary, all students achieve some breadth of study outside of the ECE department by taking a minimum of one Computer Science and 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.) 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, and probability. To see which specific courses fulfill these math requirements, please consult the mathematics course descriptions, and your academic advisor.

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

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

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

MINOR IN ELECTRICAL AND COMPUTER ENGINEERING

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

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

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

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

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

ENGINEERING SCIENCE COURSES

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

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

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

ENVIRONMENTAL ENGINEERING

DIRECTOR: J. PLUMMER (CEE)
ASSOCIATED FACULTY: J. Bergendahl (CEE), T. Camesano (CHE), D. DiBiasio (CHE), F. Hart (CEE), S. LePage (CEE), P. Mathiesen (CEE), M. Tao (CEE), 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 Program Educational Objectives for the Bachelor degree in Environmental Engineering are that our alumni will:

1. Have successful careers in environmental engineering and related professions, where sound science and engineering principles are applied to solve environmental problems in a socially and ethically responsible manner.
2. Be leaders who are at the forefront of environmental change for the betterment of ecosystems and quality of life.
### ENVIRONMENTAL ENGINEERING PROGRAM CHART

Students earning an ABET accredited bachelor degree in Environmental Engineering must complete a minimum of 15 units of study, distributed as follows:

#### MATHEMATICS AND BASIC SCIENCE (4 Units Required)
- Differential and integral calculus; differential equations \( 5/3 \) units
- Statistics (MA 2611 recommended) \( 1/3 \) unit
- Biology (BB) \( 1/3 \) unit
- Chemistry (CH) \( 3/3 \) units
- Earth science (GE 2341 recommended) \( 1/3 \) unit
- Physics (PH) \( 1/3 \) unit

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

#### ENGINEERING SCIENCE AND DESIGN (6 Units Required; 5 1/3 units as arranged below plus 2/3 units free electives in ES&D at the 2000-level or above).
Please consult the program distribution requirements for detailed information on course requirements and selection.

**Project** must include 2/3 units with laboratory experimentation.

<table>
<thead>
<tr>
<th>Engineering Science</th>
<th>minimum 2/3 units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermofluids</strong></td>
<td></td>
</tr>
<tr>
<td>ES 3001 Introduction to Thermodynamics (or CHE 2013 or CH 3510)</td>
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<tr>
<td>ES 3002 Mass Transfer</td>
<td></td>
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<tr>
<td>ES 3004 Fluid Mechanics</td>
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<tr>
<td><strong>Mechanics and Materials</strong></td>
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<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>
<td></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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</tbody>
</table>

<table>
<thead>
<tr>
<th>Core Environmental Engineering</th>
<th>minimum 3/3 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHE 2011 Chemical Engineering Fundamentals</td>
<td></td>
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<tr>
<td>CE 3059 Environmental Engineering</td>
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<tr>
<td>CE 3062 Hydraulics in Civil Engineering</td>
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<tr>
<td>CHE 3201 Kinetics and Reactor Design</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Environmental Engineering Electives</th>
<th>minimum 3/3 units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Quality and Resources</strong></td>
<td></td>
</tr>
<tr>
<td>CE 3060 Water Treatment</td>
<td></td>
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<tr>
<td>CE 3061 Wastewater Treatment</td>
<td></td>
</tr>
<tr>
<td>CE 4060 Environmental Engineering Laboratory</td>
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</tr>
<tr>
<td>CE 4061 Hydrology</td>
<td></td>
</tr>
<tr>
<td><strong>Air and Land Environmental Systems</strong></td>
<td>minimum 2/3 units</td>
</tr>
<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>CE/CHE 4063 Transport and Transformations in the Environment</td>
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<tr>
<td>CHE 3920 Air Quality Management</td>
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<tr>
<td>CHE 4401 Unit Operations of Chemical Engineering I</td>
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</table>

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

| Major Qualifying Project            | 3/3 units         |

#### ADDITIONAL DEGREE REQUIREMENTS (4 units Required)
- Humanities and Arts \( 6/3 \) units
- Social Science‡ \( 2/3 \) units
- IQP \( 3/3 \) units
- Physical Education \( 1/3 \) unit

‡ Many SS courses complement topics in environmental engineering. Courses in policy, regulations, law and environmental problems are recommended.
3. Meet the changing needs of the profession through lifelong learning, such as graduate education, engagement in the profession and organizations, and attainment of professional licensure.

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**

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics and Basic Science</td>
<td>4</td>
</tr>
<tr>
<td>2. Advanced Science (Note 2)</td>
<td>1</td>
</tr>
<tr>
<td>3. Engineering Science and Design (Includes MQP)</td>
<td>6</td>
</tr>
</tbody>
</table>

**NOTES:**

1. Mathematics and Basic Science
   a. Must include 6/3 units of mathematics, including differential and integral calculus, differential equations, and statistics.
   b. Must include 6/3 units of basic science, including 1/3 unit of biology (BB), 3/3 units of chemistry (CH), 1/3 unit of earth science (GE 2341 recommended) and 1/3 unit of PH (calculus based).

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

3. Engineering Science and Design
   a. Must include 2/3 units in thermofluids, including 1/3 unit in fluid mechanics (ES 3004 recommended) and 1/3 unit in thermodynamics (ES 3001, CHE 2013, or CH 3510).
   b. Must include 2/3 units in mechanics and materials (CE 2000 or ES 2501, CE 2001 or ES 2502, ES 2001, ES 2503).
   c. Must include 3/3 units of Core Environmental Engineering (CHE 2011, CE 3059, CE 3062, CHE 3201).
   d. Must include 6/3 units in Environmental Engineering Electives, arranged as follows: 3/3 units in water quality and resources, 2/3 units in air and land environmental systems, and 1/3 unit in environmental management.
   e. Must include 1/3 unit of environmental health issues (CE 3059, CE 3060, CE 3061, or appropriate experience through MQP, independent study, or appropriate consortium courses).
   f. Must include 2/3 units with laboratory experimentation. Must include either CE 4060 or CHE 4401. The remaining 1/3 unit may be CE 4060, CHE 4401, laboratory courses in CH (CH 2640 or CH 2650, which would satisfy Advanced Science course requirements), CE 3026, or CE 2020.
   g. Must include 1/3 unit major design experience through the MQP, or other approved design experience in a course such as CHE 4403 or ME 4429.

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

ENVIRONMENTAL AND SUSTAINABILITY STUDIES
(BACHELOR OF ARTS DEGREE)

DIRECTOR: R. KRUEGER
ASSOCIATED FACULTY: M. Bakermans, CEE; C. Clark, HUA; D. DiBiasio, CHE; J. Doyle, SSPS; L. Elgert, SSPS; R. Gottlieb, HUA; F. Looft, ECE; J. MacDonald, CBC; L. Mathews, BB; C. Peet, IGSD; J.D. Plummer, CEE; R. Rao, BB; K. Rissmiller, SSPS/IGSD; T. Robertson, HUA; D. Rosbach, BB; K. Saeed, SSPS; J. Sanbonmatsu, HUA; I. Shockey, IGSD; S. Tuler, IGSD

MISSION STATEMENT
With a growing public demand for governments and the private sector to focus greater attention on the implications of human production and consumption for environmental sustainability, professionals educated in aspects of human-environment interactions will be in increasing demand. Through core courses, projects, and seminars focused on integrated approaches to environmental issues, the environmental studies curriculum helps students to address contemporary environmental problems in creative ways that transcend disciplinary boundaries. This interdisciplinary approach also equates students to gain breadth and depth of knowledge in core disciplines such as biology, chemistry, philosophy, history and environmental law and policy.

Graduates will have strong, marketable skills translatable into graduate school, law school, or a professional environmental position upon graduation.
EDUCATIONAL OUTCOMES
Graduating Students will:
1. Be able to identify, analyze, and develop solutions to environmental problems creatively through sustained, multi-faceted 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 or Humanities (Note 5)</td>
<td>2</td>
</tr>
<tr>
<td>6. MQP</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>10 2/3</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.

MINOR IN ENVIRONMENTAL AND SUSTAINABILITY STUDIES

Students taking minors in environmental studies are expected to designate a member of the Environmental Studies affiliated faculty as their SS minor advisor, who will assist them in preparing a program that meets the requirements of the minor. Students can obtain assistance at the Environmental Studies Program office in designating an advisor.

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental Studies Core (Note 1)</td>
<td>2/3</td>
</tr>
<tr>
<td>Environmental Social Science and Humanities (Note 2)</td>
<td>1</td>
</tr>
<tr>
<td>Environmental Studies Capstone (Note 3)</td>
<td>1/3</td>
</tr>
</tbody>
</table>

NOTES
1. Only courses with the prefix ENV count toward this requirement.
2. Students must either select courses for breadth, or they may choose a thematic set of courses for depth. At least two of these courses should be above the 2000 level. Additional ENV courses not counted toward the core requirement may be counted here. Students may substitute up to two courses in environmental science with the approval of the Environmental Studies Program Review Committee.
3. The capstone requirement will normally be met by taking ENV4400, Senior Seminar in Environmental Studies. With the approval of the Program Review Committee, the capstone requirement may also be fulfilled via independent study. Students are also strongly encouraged to do an environmental/sustainability related IQP.

APPROVED SOCIAL SCIENCE AND HUMANITIES COURSES

<table>
<thead>
<tr>
<th>COURSE</th>
<th>TITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECON 2117</td>
<td>Environmental Economics</td>
</tr>
<tr>
<td>GOV 2311</td>
<td>Environmental Policy and Law</td>
</tr>
<tr>
<td>GOV 2312</td>
<td>International Environmental Policy</td>
</tr>
<tr>
<td>PY 2717</td>
<td>Philosophy and the Environment</td>
</tr>
<tr>
<td>HI 2401</td>
<td>U. S. Environmental History</td>
</tr>
<tr>
<td>ECON 2125</td>
<td>Development Economics</td>
</tr>
<tr>
<td>EN 2235</td>
<td>American Literature and the Environment</td>
</tr>
<tr>
<td>HI 2351</td>
<td>History of Ecology</td>
</tr>
<tr>
<td>HI 3317</td>
<td>Topics in Environmental History</td>
</tr>
<tr>
<td>SD 1510</td>
<td>Introduction to System Dynamics Modeling</td>
</tr>
</tbody>
</table>

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Two examples of sequences that satisfy the requirements for an ENV minor:

**ENV MINOR WITH BREADTH**
- Environmental Studies Core: 2/3
- Environmental Studies Capstone: 1/3
- BB 2040 Ecology: 1/3
- HI 2401 US Environmental History: 1/3
- ECON 2117 Environmental Economics: 1/3

**ENV MINOR WITH DEPTH (SOCIAL SCIENCE)**
- Environmental Studies Core: 2/3
- Environmental Studies Capstone: 1/3
- GOV 2311 Env Law and Policy: 1/3
- GOV 2312 Int'l Env Law and Policy: 1/3
- ECON 2117 Environmental Economics: 1/3

Many other sequences are possible.

**FIRE PROTECTION ENGINEERING**

**T. EL-KORCHI, HEAD**

PROFESSOR: N. A. Dembsey
ASSOCIATE PROFESSORS: L. Albano, B. Meacham, K. A. Notarianni
ASSISTANT PROFESSORS: A. Rangwala, A. Simeoni
PROFESSOR OF PRACTICE: M. Puchovsky
FPE EMERITUS: R. W. Fitzgerald, D. A. Lucht, R. E. Zalosh
ADJUNCT FPE FACULTY: J. Averill, D. Sheppard, J. Tubbs, C. Wood

**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.
CONCENTRATIONS FOR HUMANITIES AND ARTS MAJORS

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

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

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

REQUIREMENTS

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

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

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

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

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

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

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

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

**Humanities and Arts with Art 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:**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>HI 2311</td>
<td>American Colonial History</td>
</tr>
<tr>
<td>HI 2313</td>
<td>American History, 1789-1877</td>
</tr>
<tr>
<td>HI 2314</td>
<td>American History, 1877-1920</td>
</tr>
<tr>
<td>HI 2315</td>
<td>The Shaping of Post-1920 America</td>
</tr>
<tr>
<td>HI 2316</td>
<td>American Foreign Policy from Woodrow Wilson</td>
</tr>
</tbody>
</table>

Return to Table of Contents
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
GOV 2302  Science-Technology Policy
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 2114  Modern Architecture in the American Age
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 the methods of the humanities and social sciences to the study of science and technology.

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

List 1: Designated HSST Courses
EN 2252  Science and Scientists in Modern Literature
EN 3215  Genres of Science Writing
HI 1331  Introduction to the History of Science
HI 1332  Introduction to the History of Technology
HI 2331  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-Technology Debate
GOV 2302  Science-Technology 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.

PROFESSIONAL WRITING

CO-DIRECTORS: C. DEMETRY (ME) and J. DEWINTER (HUA)
ASSOCIATED FACULTY: E. Boucher (HUA), M. Elmes (MG), B. Faber (HUA & MG), L. Higgins (HUA), A. Madan (HUA), R. Madan (HUA), A. Rivera (HUA), R. Smith (HUA)

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

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

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

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

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

Program Distribution Requirements for the Professional Writing Major

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Scientific and/or technical concentration (Note 1)</td>
<td>6</td>
</tr>
<tr>
<td>2. Writing and Rhetoric (WR) concentration (Note 2)</td>
<td>3</td>
</tr>
<tr>
<td>3. MQP (Note 3)</td>
<td>1</td>
</tr>
</tbody>
</table>

NOTES:

1. The student’s scientific and/or technical concentration must be a plan of study, approved by the student’s program review committee, with a clear underlying rationale in mathematics, basic science, computer science, engineering, and/or management

2. The Writing and Rhetoric concentration consists of 3 units from the 2 following categories.
   a. Writing and Rhetoric (2 units) from any of the existing WR courses or equivalent ISPs. This must include WR 3112: Rhetorical Theory unless a substitution is authorized by the student’s program review committee, which will be granted only under unusual circumstances. No more than one course at the 1000-level can be applied, and students must complete at least one 4000-level course in WR.
   b. Electives (1 unit)
      The 1 unit of electives must be defined and approved by the student’s program review committee. Students may draw on:
      - Courses in Writing and Rhetoric not used to fulfill the above 2 units requirement;
      - Courses in science, technology, and culture studies (such as AR/ID 3150, CS 3041, CS 3043, EN 2252, HI 2334, HI 2402, HI 3331, HI 3333, HI 3334, IMGD 2000, IMGD 2001, GOV 2302, PSY 2406, STS 2208);
      - Philosophy and ethics courses (such as PY 2711, PY 2713, PY 2714, PY 2716, PY 2717, PY/RE 2731, PY/RE 3731);
      - Foreign language courses;
      - Business courses (such as BUS 2080, BUS 3010, BUS 4030, OBC 3354, OIE 3420, OBC 4366, MIS 3720, MIS 3740, MIS 4781);

3. The MQP should build on the student’s scientific and technical concentration while articulating a problem within professional writing.

HUMANITIES AND ARTS MINORS

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

DRAMA/THEATRE

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

Because 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 Performance 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 may be applied to the Drama/Theatre minor. The final Inquiry Seminar or Practicum may not be counted toward the minor.

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

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

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

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

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

**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).

**HISTORY**

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

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

**MUSIC**

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, the 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**

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 Jennifer deWinter (jdewinter@wpi.edu) for more information.

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

1. 1/3 unit. Core course in Writing and Rhetoric: WR 3112 or equivalent.
2. 1-1/3 unit. Electives in writing and rhetoric (WR). If there is good reason, and with the approval of the Program Review Committee, electives may also include courses in art history, literature (in English or other languages), and philosophy and religion.
3. 1/3 unit. Capstone course WR 4111 unless an Independent Study Project (ISP) substitution is authorized by the student’s program review committee, and will be granted only under unusual circumstances. Should students receive permission to complete the capstone with an ISP, then those students should submit and have approved a one-page proposal for their capstone to the Program Review Committee the term before they intend to complete it.

No more than 1 unit of course work may be double-counted toward the Humanities and Arts Requirement. Students interested in this area also may wish to consider the major in Professional Writing (see catalog rules for minors).

**INTERACTIVE MEDIA & GAME DEVELOPMENT**

**DIRECTOR: R. LINDEMAN (CS)**
**CO-DIRECTOR: J. ROSENSTOCK (HUA)**

**ASSOCIATED FACULTY:** E. Agu (CS), L. Arroyo (SSPS), F. Bianchi (HUA), L. Boudreau (HUA), M. Claypool (CS), D. Cyganski (ECE), J. deWinter (HUA), J. Farbrook (HUA), D. Finkel (CS), J. Forgeng (HUA), N. Hefferman (CS), R. Lindeman (CS), B. Moriarty (IMGD), D. O’Donnell (IMGD), G. Phillips (PH), C. Rich (CS), J. Rosenstock (HUA), B. Snyder (IMGD), J. Sanbonmatsu (HUA), R. Sutter (IMGD), C. Wills (CS), K. Zizza (IMGD)

**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 team-based, multi-term 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.
10. Successfully complete team-based, full-term IMGD projects.

**Program Distribution Requirements for the Interactive Media & Game Development Major**

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core IMGD (Note 1)</td>
<td>2/3</td>
</tr>
<tr>
<td>Math</td>
<td>1/3</td>
</tr>
<tr>
<td>Science</td>
<td>1/3</td>
</tr>
<tr>
<td>Computer Science (Note 2)</td>
<td>1/3</td>
</tr>
<tr>
<td>Social and Philosophical Issues (Note 3)</td>
<td>1/3</td>
</tr>
<tr>
<td>Studio Art (Note 4)</td>
<td>1/3</td>
</tr>
<tr>
<td>Game Audio (Note 5)</td>
<td>1/3</td>
</tr>
<tr>
<td>English (Note 6)</td>
<td>1/3</td>
</tr>
<tr>
<td>IMGD (Note 7)</td>
<td>5/3</td>
</tr>
<tr>
<td>Major Qualifying Project</td>
<td>3/3</td>
</tr>
</tbody>
</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):

<table>
<thead>
<tr>
<th>AREA</th>
<th>MINIMUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer Science (Note 8)</td>
<td>10/3</td>
</tr>
<tr>
<td>Visual Arts (Notes 9, 10, 11, 12, 13)</td>
<td>10/3</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>ELECTIVES</th>
<th>MINIMUM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Electives (Note 14)</td>
<td>3/3</td>
</tr>
</tbody>
</table>

**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 any audio course with an IMGD prefix.
6. Courses with the prefix EN, WR or RH.
7. Must include (IMGD 3000 and IMGD 4000) or (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. 3/3 from Humanities and Arts or IMGD.
10. 1/3 from Art History.
11. 6/3 from Visual Arts, chosen from the following list:
   • Essentials of Art (AR 1100) or Digital Imaging and Computer Art (AR 1101) (whichever was not taken for the Studio Art requirement – Note 4)
   • Figure Drawing (AR 2202)
   • Digital Painting (IMGD 2700/AR 2700)
   • 3D Modeling (IMGD 2101/AR 2101)
   • 3D Modeling II (IMGD 3101/AR 3101)
   • The Art of Animation (IMGD 2201/AR 2201)
   • Animation II (IMGD 3201/AR 3201)
   • Concept Art and Creative Illustration (IMGD 3700/AR 3700)

12. At least 5/3 units at the 2000-level or higher.

13. Students completing the Artistic (Humanities and Arts) Area Requirement must complete a Technical Requirement, described below.

14. Electives must be chosen from the following areas: Computer Science, Humanities and Arts, Interactive Media & Game Development, Mathematics, Science, Social Science, Management.

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.

MINOR IN INTERACTIVE MEDIA & GAME DEVELOPMENT

The Interactive Media & Game Development Minor is for students who, for personal or career purposes, wish to earn official recognition of their achievements in IMGD, but do not have academic time to fulfill the requirements for the major.

A total of six IMGD courses are required for the Minor degree requirement. This consists of:

Two core IMGD courses from this list:
   • IMGD 1000. Critical Studies of Interactive Media and Games
   • IMGD 1001. The Game Development Process
   • IMGD 1002. Storytelling in Interactive Media and Games

Three additional IMGD courses. If necessary for the academic goals of a student’s minor program, and with prior approval of the IMGD Minor Coordinator, may include one course in art history, visual art, creative writing and rhetoric, theatre, or music.

One 3000 or higher level IMGD course as a final capstone.

General WPI rules that apply to the Minor are that at most three courses can be double-counted for any other degree requirement, and the capstone course cannot be a double-counted course.

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

Sample Programs of Study:

Visual Art
   IMGD 1001. The Game Development Process
   IMGD 1002. Storytelling in Interactive Media and Games
   IMGD 2101/AR 2101. 3D Modeling I
   IMGD 2700/AR 2700. Digital Painting
   IMGD 3101/AR 3101. 3D Modeling II
   IMGD 3700 Concept Art and Creative Illustration

Creative Writing/Game Design
   IMGD 1000. Critical Studies of Interactive Media and Games
   IMGD 1002. Storytelling in Interactive Media and Games
   IMGD 2500. Design of Tabletop Strategy Games
   IMGD 2900. Digital Game Design I
   RH 3211. Rhetoric of Visual Design

Animation
   IMGD 1001. The Game Development Process
   IMGD 1002. Storytelling in Interactive Media and Games
   IMGD 2101/AR 2101. 3D Modeling I
   IMGD 2201/AR 2201. The Art of Animation I
   IMGD 3201. Animation II

Audio Arts
   IMGD 1000. Critical Studies of Interactive Media and Games
   IMGD 1001. The Game Development Process
   IMGD 2030. Game Audio I
   IMGD 3200/AR 3200. Interactive Electronic Arts
   IMGD 3500 Artistic Game Development I
   IMGD 302x. Game Audio II

Technical Development
   IMGD 1000. Critical Studies of Interactive Media Games
   IMGD 1001. The Game Development Process
   IMGD 3000. Technical Game Development I
   IMGD 4000. Technical Game Development II
   IMGD 3100. Novel Interfaces For Interactive Environments
   IMGD 4100. Artificial Intelligence for Interactive Media and Games

Game Studies
   IMGD 1000. Critical Studies of Interactive Media and Games
   IMGD 1001. The Game Development Process
   IMGD 1002. Storytelling in Interactive Media and Games
   IMGD 2000. Social Issues in Interactive Media and Games
   IMGD 2001. Philosophy and Ethics of Computer Games
   IMGD 4200. History and Future of Immersive and Interactive Media
2. The Dean of the Interdisciplinary and Global Studies (IGSD), Prof. Richard Vaz, will determine, with the assistance of the student’s advisor. The student should then consult with the dean of the program to discuss how WPI can assist you in reaching your goals.

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 proposal, as finally accepted by the committee, 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.

### Minor in International and Global Studies

The minor in International and Global Studies offers students the opportunity to integrate coursework on campus with a global educational experience. Students interested in the minor should meet with faculty associated with International and Global Studies as early as possible. They will be assigned an advisor after completing a minor declaration form. The International and Global Studies minor consists of two units of work distributed in the following way:

1. 2/3 unit International and Global Core. Any courses with the INTL prefix or courses selected from international and global history or social science courses (see below).

2. 1 unit International and Global Electives. These may be selected from among international and global courses in the humanities, social sciences, or business. These may include:
   - any INTL courses;
   - any international and global history or social science courses (see below);
• any foreign language courses (e.g., AB, CN, GN, SP);
• 1/3 unit first-year course (e.g., FY 1100);
• International and global courses in business (e.g., BUS 1020), art history (e.g., AR 1111), literature (e.g., EN 3222), music history (e.g., MU 3001), philosophy (e.g., PY 2716), religion (e.g., RE 2724), and writing, and other courses approved by the Program Review Committee. Electives may not include the MQP.

3. 1/3 unit Senior Seminar in International and Global Studies (INTL 4100). This seminar may be taken at any time after an International and Global Experience. With the approval of the Program Review Committee, the seminar may be completed via independent study.

4. International and Global Experience. All International and Global Studies minors are required to have a study abroad experience that should be educational in nature and equivalent in length to at least one WPI term. All WPI global projects and exchange programs completed at projects centers outside of the United States meet this requirement. If approved by the Program Review Committee, global projects completed in the United States or international educational programs and/or internships sponsored by other organizations also may satisfy this requirement.

WPI policy requires that no more than one unit of coursework can be double counted toward other degree requirements. Thus, students may count three courses for the minor taken to fulfill other degree requirements (such as the Humanities and Arts Requirement or two course requirement in the Social Sciences) as long as one unit of the minor does not double-count. In other words, students must take INTL 4100 and two other courses for this minor that do not count for another degree requirement.

International and Global History Courses
INTL 1100 Introduction to International and Global Studies
INTL 2100 Approaches to Global Studies
HI 1313 The US and the World
HI 1322 Introduction to European Cultural History
HI 1341 Introduction to Global History
HI 2316 Twentieth Century American Foreign Relations
HI 2320 Modern European History
HI 2324 The British Empire
HI 2325 Modern France
HI 2328 History of Revolutions in the Twentieth Century
HI 2341 Contemporary World Issues in Historical Perspective
HI 2343 East Asia: China at the Center
HI 2403 Global Environmental History
HI 2921 Topics in Modern European History
HI 3331 Topics in the History of European Science and Technology
HI 3335 Topics in the History of Non-Western Science and Technology
HI 3341 Topics in Imperial and Postcolonial History
HI 3342 Topics in Comparative Civilizations
HI 3343 Topics in Asian History
HU 1412 Introduction to Asia
HU 2340 Popular Culture and Social Change in Asia
HU 2441 African History and Culture

International and Global Social Science Courses
ECON 1120 Introductory Macroeconomics
ECON 2125 Development Economics
ENV 1100 Introduction to Environmental Studies
ENV 2600 Environmental Problems in the Developing World
GOV 1320 Topics in International Politics
GOV 2312 International Environmental Policy
GOV 2319 Global Environmental Politics
ID 2050 Social Science Research for the IQP
PSY 2406 Cross-Cultural Psychology: Human Behavior in Global Perspective
SOC 1202 Introduction to Sociology and Cultural Diversity

Distribution Requirements for the International and Global Studies Major:

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>International and Global Core (Note 1)</td>
<td>1</td>
</tr>
<tr>
<td>International and Global Fields (Note 2)</td>
<td>4</td>
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<tr>
<td>International and Global Experience (Note 3)</td>
<td>0</td>
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<tr>
<td>Science, Technology, Engineering, Mathematics (Note 4)</td>
<td>2</td>
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<tr>
<td>Electives (Note 5)</td>
<td>2</td>
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<tr>
<td>MQP</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
</tr>
</tbody>
</table>

NOTES:
1. Only courses with the prefix INTL count toward this requirement. Must include the senior seminar in international and global studies.
2. International and Global Fields: Majors complete at least one unit of work in each of the following areas. They must also complete at least one additional unit of work in one of these areas, which will be considered their primary field.
   a) History and International and Global Studies. These include any course with the INTL prefix or any international and global history course (see list).
   b) Language, Literature, and Culture. These include any course in foreign languages, civilization, and literature offered at WPI (e.g., AB, CN, GN, SP), or in the Consortium with the prior approval of the Program Review Committee; also courses approved by the Program Review Committee in Art History (e.g., AR 1111, AR 3112), English Literature (e.g., EN 2251, EN 3222), Music History (e.g., MU 3001), Philosophy (e.g., PY 2716), Religion (e.g., RE 2724), or Writing. Majors who designate Language, Literature, and Culture as their primary field should take most of their courses in a single discipline or in a coherent program approved by the Program Review Committee.
   c) Social Sciences and Business. These include international and global social sciences courses (see list), international and global courses in business (e.g., BUS 1020), and 1/3 unit of a first-year course (e.g., FY 1100). Students may count courses taken for the two-course requirement in Social Sciences.
3. International Studies majors are required to have a study-abroad experience. (In very unusual cases exceptions may be made to this requirement but only with prior approval of the Director and Program Review Committee). This abroad experience may take the form of a project, exchange, or internship approved by the Program Review Committee. The study-abroad experience should be educational in nature and equivalent in length to at least one WPI term.
4. Must include a minimum of 2/3 units in mathematics or computer science and 2/3 units in natural science or engineering science. The remaining 2/3 units may be from any area of mathematics, computer science, natural science or engineering science. Double majors may count courses taken for their other major.
5. Electives may be from any area except Air Force Aerospace Studies, Military Science or Physical Education. Double-majors may count courses taken for their other major.
DOUBLE MAJOR IN INTERNATIONAL AND GLOBAL STUDIES
Students may pursue a double major in International and Global Studies and any area of study at WPI except a major in Humanities and Arts. To pursue the double major, a student must satisfy all of the degree requirements for both disciplines, including an MQP and Distribution Requirements. The double major in International and Global Studies requires the same distribution of courses as the major and either a second MQP in International and Global Studies or an interdisciplinary MQP that satisfies the requirement of both programs as described on page 12. Double majors are also required to have an International and Global Experience.

INTERNATIONAL AND GLOBAL EXPERIENCES
An International and Global Experience may take the form of an international and global IQP, MQP, Humanities and Arts Inquiry Seminar, internship or exchange program. Students often plan their international and global experience in their Sophomore year. All students are advised to consult the list of projects offered at WPI's Global Project Centers. Each fall, the projects and exchange programs for the following year are widely advertised on campus. For information about student exchange programs, see page 211.

Award-winning projects at WPI are frequently on international topics. International and Global Studies offers the opportunity not only to complete some of the highest quality projects at WPI, but also to offer solutions to some of the most challenging problems in the world.

Students interested in International and Global Studies may ask any member of the Associated Faculty for more information, or they may consult our webpages http://www.wpi.edu/+IN/.

LIBERAL ARTS AND ENGINEERING
(BACHELOR OF ARTS DEGREE)

DIRECTORS: J. ORR (ECE), L. SCHACHTERLE (HU)
ASSOCIATED FACULTY and PROGRAM COMMITTEE:
F. Bianchi (HU), D. DiBiasio (ChE), J. Doyle (SSPS),
P. Hansen (HU), F. Hart (CEE), S. Jiusto (IGSD), R. Krueger (SSPS),
T. Padir (ECE), K. Rissmiller (IGSD and SSPS), D. Samson (HU),
K. Stafford (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 and global studies, business, or wherever a solid technical background would give them a unique edge. The program is also designed to allow students to transfer to an engineering BS program with minimum loss of time.

For more information, see the Admissions web site at 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 further study in engineering but also for many other high-level careers, such as:

- Law
- Medicine and health care
- Energy policy
- Environmental policy
- Technology policy
- Finance
- Technology management
- International relations
- Public affairs and political service
- Performing arts, especially in music
- Consulting

PROGRAM OUTCOMES
Graduates of the BA in Liberal Arts and Engineering major will have:

a) an ability to formulate and solve problems requiring knowledge of both technological and societal/humanistic needs and constraints
b) an ability to apply, as needed, the relevant fundamentals of mathematics, science, engineering, social sciences, and the humanities to solve such problems
c) an ability to use the techniques, skills, and modern tools necessary for professional practice
d) an ability to function on multi-disciplinary teams
e) an understanding of professional and ethical responsibility
f) an ability to communicate effectively in oral, written and visual modes
g) a recognition of the need for, and ability to engage in, life-long learning, in response to the ever-increasing pace of change affecting societal needs and opportunities
h) the broad educational 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>
<td>3</td>
</tr>
<tr>
<td>2. Engineering Science and Design (Notes 3, 4, 5)</td>
<td>3</td>
</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>
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</table>
Table 1: BA in Liberal Arts and Engineering

Three (3) examples; others possible

<table>
<thead>
<tr>
<th>15 Units</th>
<th>ECE Design</th>
<th>Energy and Environment</th>
<th>Engineering and Pre-Law</th>
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<tbody>
<tr>
<td>WPI General Education Institutional Requirements (5 Units)</td>
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<tr>
<td>1 H&amp;A</td>
<td>HU&amp;A of student’s choice</td>
<td>HI 1332</td>
<td>HI 2317</td>
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<td>2 H&amp;A</td>
<td>HU&amp;A</td>
<td>HI 2324</td>
<td>EN/WR 2211</td>
</tr>
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<td>3 H&amp;A</td>
<td>HU&amp;A</td>
<td>HI 2331</td>
<td>EN/WR 3214</td>
</tr>
<tr>
<td>4 H&amp;A</td>
<td>HU&amp;A</td>
<td>HI 2334</td>
<td>EN/WR 3216</td>
</tr>
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<td>5 H&amp;A</td>
<td>HU&amp;A</td>
<td>HI 3331</td>
<td>RH 3112</td>
</tr>
<tr>
<td>6 H&amp;A</td>
<td>HU 3900 or HU 3910</td>
<td>HU 3900 or HU 3910</td>
<td>HU 3900 or HU 3910</td>
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<tr>
<td>7 SS</td>
<td>SS</td>
<td>PSY 1402</td>
<td>SOC 1202</td>
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<td>8 SS</td>
<td>SS</td>
<td>SS/ID 2050</td>
<td>GOV 1301</td>
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<td>9 PE</td>
<td>PE</td>
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<td>10 Free Elective</td>
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<td>11 Free Elective</td>
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<td>16 Math &amp; Science</td>
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<td>17 Math &amp; Science</td>
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<td>18 Math &amp; Science</td>
<td>MA 1024</td>
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<td>19 Math &amp; Science</td>
<td>MA 2051</td>
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<td>20 Math &amp; Science</td>
<td>MA 2611</td>
<td>MA 2611</td>
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<td>21 Math &amp; Science</td>
<td>CH 1010</td>
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<td>22 Math &amp; Science</td>
<td>PH 1110</td>
<td>CH 1020</td>
<td>BB 1035</td>
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<td>23 Math &amp; Science</td>
<td>PH 1120</td>
<td>BB 1002</td>
<td>PH 1110</td>
</tr>
<tr>
<td>24 Math &amp; Science</td>
<td>BB 1001</td>
<td>PH 1110</td>
<td>PH 1120</td>
</tr>
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<td>Engineering Studies Cornerstone (3 Units)</td>
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<td>Theme</td>
<td>ECE</td>
<td>Energy</td>
<td>Eng Science and Design</td>
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<td>26 Engineering Sci/Des</td>
<td>ECE 2019</td>
<td>ES 3003</td>
<td>ES 1310</td>
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<td>28 Engineering Sci/Des</td>
<td>ECE 2049</td>
<td>ES 2501</td>
<td>ES 2501</td>
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<td>29 Engineering Sci/Des</td>
<td>ECE 2112</td>
<td>ECE 2010</td>
<td>ES 2502</td>
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<td>30 Engineering Sci/Des</td>
<td>ECE 2201</td>
<td>ECE 2019</td>
<td>ES 2503</td>
</tr>
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<td>31 Engineering Sci/Des</td>
<td>ECE 2311</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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<td>33 Engineering Sci/Des</td>
<td>CS 1101</td>
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<td>Liberal Arts Cornerstone (3 Units)</td>
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<tr>
<td>Theme</td>
<td>Social, Humanistic, Business Factors of Design</td>
<td>Environment and Policy</td>
<td>Pre Law</td>
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<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>
</tr>
<tr>
<td>36 Liberal Studies</td>
<td>HI 3331 Topics in Society/Technology Studies</td>
<td>ENV 2400 Environmental Problems</td>
<td>GOV 2313 Intellectual Property Law</td>
</tr>
<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>
</tr>
<tr>
<td>38 Liberal Studies</td>
<td>GOV 2302 Science and Technology Policy</td>
<td>HI 3333 American Technology 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 Technological 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>ENV 1100 Introduction to Environmental Studies</td>
<td>BUS 2020 Legal Environment of Business Decisions</td>
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<tr>
<td>42 Liberal Studies</td>
<td>ETR 3910 Recognizing and Evaluating New Venture Opportunities</td>
<td>ENV 4400 Senior Seminar in Environmental Studies</td>
<td>FIN 2250 Financial System of the US</td>
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<td>MQP – aimed at confluence of engineering and liberal arts cornerstones (1 Unit)</td>
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<tr>
<td>43 MQP</td>
<td>MQP</td>
<td>MQP</td>
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<td>44 MQP</td>
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<tr>
<td>45 MQP</td>
<td>MQP</td>
<td>MQP</td>
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</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 1/3 Unit each of BB, CH, and PH.
3. Courses with prefixes AREN, BME, CE, CHE, CS, ECE, ES, ME, and RBE are eligible to count toward this requirement. These courses should be thematically related; students must gain approval of their program of study in this area from the Liberal Arts and Engineering Program Committee.
4. Must include either CS 1101 or CS 1102.
5. Must include at least one course in engineering design (such as ECE 2799 or ME 2300), plus at least two other courses with a significant laboratory component (a list of such courses will be maintained by the Liberal Arts and Engineering Program Committee).
6. Must include 2 Units of Humanities and Arts and Social Science. Courses with prefixes AR, HI, MU, PY, RH, WR, IMGD, ECON, GOV, PSY, STS, and SD may be eligible to count toward this requirement. Courses must be selected from areas that strongly complement the practice of engineering, such as the history of technology, ethics, writing and visual rhetoric, economics, society-technology studies, and environmental studies. A list of such courses will be maintained by the Liberal Arts and Engineering Program Committee.
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.

MATHEMATICAL SCIENCES
L. CAPOGNA, HEAD; J. PETRUCCELLI, ASSOCIATE HEAD
ASSISTANT PROFESSORS: M. Bichuch, S. Olson, S. Sturm, Z. Wu, Z. Zhang, J. Zou
VISITING ASSOCIATE PROFESSOR: R. Paffenroth
PROFESSOR OF PRACTICE: J. Abraham
TEACHING PROFESSOR: J. Goulet
TEACHING ASSOCIATE PROFESSOR: M. Blais
TEACHING ASSISTANT PROFESSORS: M. Johnson, V. Yakovlev
POSTDOCTORAL SCHOLARS: F. Abdullayer, Q. Han, J. Huang, S. Kim, B. Peiris, M. Rostani

MISSION STATEMENT
Recognizing the vital role that mathematical sciences play in today's society, the Mathematical Sciences Department provides leading-edge programs in education, research, and professional training in applied and computational mathematics and statistics. These programs are enhanced and distinguished by project-oriented education and collaborative involvement with industry, national research centers, and the international academic community.

PROGRAM EDUCATIONAL OBJECTIVES
The department's major programs provide students with preparation for effective and successful professional careers in the mathematical sciences, whether in traditional academic pursuits or in the many new career areas available in today's technologically sophisticated, globally interdependent society. Through course work, students acquire a firm grounding in fundamental mathematics and selected areas of emphasis. Projects, which often involve interdisciplinary and industrial applications, offer further opportunities to gain mathematical depth and to develop skills in problem-solving, communication, teamwork, and self-directed learning, together with an understanding of the role of the mathematical sciences in the contemporary world.

PROGRAM OUTCOMES
We expect graduates to:
1. have a solid knowledge of a broad range of mathematical principles and techniques and the ability to apply them.
2. be able to read, write, and communicate mathematics inside and outside the discipline.
3. have the ability to formulate mathematical statements and prove or disprove them.
4. be able to formulate and investigate mathematical questions and conjectures.
5. understand fundamental axiom systems and essential definitions and theorems.
6. be able to formulate and analyze mathematical or statistical models.
7. have the ability to apply appropriate computational technology to analyze and solve mathematical problems.
8. be able to learn independently and as part of a team, and to demonstrate a depth of knowledge in at least one area of the mathematical sciences.

The Department of Mathematical Sciences at WPI offers:
   i) the Bachelor of Science degree in Mathematical Sciences;
   ii) the Bachelor of Science degree in Actuarial Mathematics;
   iii) a Minor in Mathematics;
   iv) a Minor in Statistics;

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>
</tr>
</thead>
<tbody>
<tr>
<td>1. Mathematics including MQP (See notes 1-4).</td>
<td>7</td>
</tr>
<tr>
<td>2. Basic Science (See note 5).</td>
<td>2/3</td>
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<tr>
<td>3. Computer Science (See note 5).</td>
<td>2/3</td>
</tr>
<tr>
<td>4. Additional courses or independent studies from other departments that are related to the student's mathematical program, to be selected from basic science, engineering, computer science or business (see Notes 5-7).</td>
<td>2/3</td>
</tr>
<tr>
<td>5. Additional courses or independent studies (except AS, MS, PE courses, and other degree requirements) from any area.</td>
<td>3/3</td>
</tr>
</tbody>
</table>

NOTES:
1. Must include MA 3831 and MA 3832, or their equivalents, at least one of MA 3257, MA 3457, or equivalent, and at least one of MA 3823, MA 3825, or equivalent.
2. Must include at least three of the following: MA 2073, MA 2271, MA 2273, MA 2431, MA 2631, or their equivalents.
3. At least 7/3 units must consist of MA courses at the 3000 level or above (the courses in Note 1 count toward this requirement).
4. May not include both MA 2631 and MA 2621.
5. Basic science courses must be chosen from the following disciplines: BB, CH, ES, GE, or PH.
6. CS courses may not include both CS 3043 and CS 2022.
7. Business courses may not include FIN 1250.

Program in Mathematical Sciences

Projects
Some of the most active career directions in the mathematical sciences are reflected in the MQP areas around which the department's offerings are organized: Algebraic and Discrete Mathematics, Computational and Applied Analysis, Operations Research, and Probability and Statistics. As early as practical, and certainly no later than the sophomore year, the mathematical sciences major should begin exploring these different areas. The transition courses, MA 2073, 2271, 2273, 2431, and 2631, are specifically designed to introduce the four MQP areas while preparing the student for advanced courses and the MQP. The student should talk to faculty in the student's area of interest to develop and select an MQP and MQP advisor.

While most students choose MQPs in one of the four areas mentioned above, it is possible to design an MQP that does not fit into any one area. In such cases, students will want to take special care to plan their programs carefully with their advisors so that sufficient background is obtained before beginning to do research. Independent studies are a good way for students to learn topics that are not taught in regularly-scheduled courses. Interested students should approach faculty with requests for independent studies.

Through the Center for Industrial Mathematics and Statistics (CIMS), students can use their mathematics and statistics training to work on real-world problems that come from sponsors in industry and finance. More information about industrial MQPs and projects can be found at http://www.wpi.edu/+CIMS.

The following sections contain, for each MQP area:
- A brief description of the area including the kinds of challenges likely to be encountered by MQP students and mathematical scientists working there.
- Courses of interest.

Algebraic and Discrete Mathematics
Algebraic and discrete mathematics is recognized as an increasingly important and vital area of mathematics. Many of the fundamental ideas of discrete mathematics play an important role in formulating and solving problems in a variety of fields ranging from ecology to computer science. For instance, graph theory has been used to study competition of species in ecosystems, to schedule traffic lights at an intersection, and to synchronize parallel processors in a computer. Coding theory has been applied to problems from the private and public sectors where encoding and decoding information securely is the goal. In turn, the problems to which discrete mathematics is applied often yield new and interesting mathematical questions. The goal of a project in discrete mathematics would be to experience this interaction between theory and application. To begin, a typical project team would assess the current state of a problem and the theory that is relevant. Once this is done, the project team's objective would be to make a contribution to solving the problem by developing new mathematical results.

In working in discrete mathematics, one may be writing algorithms, using the computer as a modeling tool, and using the computer to test conjectures. It is important that a student interested in this area have some computer proficiency. Depending on the project, an understanding of algorithm analysis and computational complexity may be helpful.

Courses of Interest

<table>
<thead>
<tr>
<th>Courses of Interest</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 2271</td>
<td>Graph Theory</td>
</tr>
<tr>
<td>MA 2273</td>
<td>Combinatorics</td>
</tr>
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<td>MA 3231</td>
<td>Linear Programming</td>
</tr>
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<td>MA 3233</td>
<td>Discrete Optimization</td>
</tr>
<tr>
<td>MA 3823</td>
<td>Group Theory</td>
</tr>
<tr>
<td>MA 3825</td>
<td>Rings and Fields</td>
</tr>
<tr>
<td>MA 4891</td>
<td>Topics in Mathematics (when appropriate)</td>
</tr>
<tr>
<td>CS 2301</td>
<td>Systems Programming for Non-Majors</td>
</tr>
<tr>
<td>CS 4120</td>
<td>Analysis of Algorithms</td>
</tr>
<tr>
<td>CS 4123</td>
<td>Theory of Computation</td>
</tr>
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</table>

Return to Table of Contents
## Mathematical Sciences Major Program Chart

### University Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Units</th>
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</thead>
<tbody>
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<td>Residency</td>
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<td>Interactive Qualifying Project</td>
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</tr>
<tr>
<td>Physical Education</td>
<td>1/3</td>
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### Foundation Courses

#### Introductory Courses
- MA 1021-1024
- MA 1020-1120
- MA 1033-1034
- MA 1971
- MA 2051
- MA 2071
- MA 2201
- MA 2210
- MA 2251
- MA 2610
- MA 2611

### Transition Courses

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<td>MA 2273*</td>
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### Core Courses

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<tr>
<td>One of MA 3257 or MA 3457</td>
<td></td>
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<tr>
<td>One of MA 3823* or MA 3825*</td>
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### Other MA Courses to Attain Total of 6 Units:

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<td>MA 2273*</td>
<td>MA 3457</td>
<td>MA 3233</td>
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<td>MA 3475*</td>
<td>MA 3825*</td>
<td>MA 3233*</td>
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<td>MA 4237*</td>
<td>MA 3627*</td>
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<td></td>
<td>MA 4451</td>
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<td>MA 3631</td>
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### Other Requirements

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<tr>
<td>Computer Science Courses</td>
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</tbody>
</table>

* Category II courses, offered in alternating years.

### Computational and Applied Analysis

This area of mathematics concerns the modeling and analysis of continuous physical or biological processes that occur frequently in science and engineering. Students interested in this area should have a solid background in analysis which includes the ability to analyze ordinary and partial differential equations through both analytical and computational means.

In most circumstances, an applied mathematician does not work alone but is part of a team consisting of scientists and engineers. The mathematician’s responsibility is to formulate a mathematical model from the problem, analyze the model, and then interpret the results in light of the experimental evidence. It is, therefore, important for students to have some experience in mathematical modeling and secure a background in one branch of science or engineering through a carefully planned sequence of courses outside of the department.

With the increase in computational power, many models previously too complicated to be solvable, can now be solved numerically. It is, therefore, recommended that students acquire enough computer proficiency to take advantage of this. Computational skills are important in applied mathematics. Students may learn these skills through various numerical analysis courses offered by the department. An MQP in this area will generally involve the modeling of a real-life problem, analyzing it, and solving it numerically.
Courses of Interest
MA 2251 Vector and Tensor Calculus
MA 2431 Mathematical Modeling with Ordinary Differential Equations
MA 3231 Linear Programming
MA 3257 Numerical Methods for Linear and Nonlinear Systems
MA 3457 Numerical Methods for Calculus and Differential Equations
MA 3471 Advanced Ordinary Differential Equations
MA 3475 Calculus of Variations
MA 4235 Mathematical Optimization
MA 4291 Applicable Complex Variables
MA 4411 Numerical Analysis of Differential Equations
MA 4451 Boundary Value Problems
MA 4473 Partial Differential Equations

OPERATIONS RESEARCH
Operations research is an area of mathematics which seeks to solve complex problems that arise in conducting and coordinating the operations of modern industry and government. Typically, operations research looks for the best or optimal solutions to a given problem. Problems within the scope of operations research methods are as diverse as finding the lowest cost school bus routing that still satisfies racial guidelines, deciding whether to build a small plant or a large plant when demand is uncertain, or determining how best to allocate timesharing access in a computer network.

Typically, these problems are solved by creating and then analyzing a mathematical model to determine an optimal strategy for the organization to follow. Often the problem requires a statistical model, and nearly always the analysis - whether optimizing through a set of equations or simulating the behavior of a process - involves the use of a computer. Finally, operations researchers must be able to interpret and apply the results of their analyses in an appropriate manner.

In addition to a solid background in calculus, probability and statistics, and the various operations research areas, prospective operations researchers should be familiar with computer programming and managerial techniques.

Courses of Interest
BUS 2080 Data Analysis for Decision Making
MA 2271 Graph Theory
MA 2273 Combinatorics
MA 3231 Linear Programming
MA 3233 Discrete Optimization
MA 3627 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 3460 Simulation Modeling and Analysis
OIE 3510 Stochastic Models

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:

<table>
<thead>
<tr>
<th>REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
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<tbody>
<tr>
<td>1. Mathematics (including MQP) (See notes 1-5)</td>
<td>7</td>
</tr>
<tr>
<td>2. Basic Science (See note 6)</td>
<td>2/3</td>
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<tr>
<td>3. Computer Science</td>
<td>2/3</td>
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<tr>
<td>4. Business (See note 7)</td>
<td>4/3</td>
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<tr>
<td>5. Additional courses or independent studies (except AS, MS, PE courses, and other degree requirements) from any area</td>
<td>1/3</td>
</tr>
</tbody>
</table>

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 include independent studies directed towards Society of Actuaries exams only if the material was not previously covered in a WPI course.
5. May not include both MA 2631 and MA 2621.
6. Basic science courses must be chosen from the following disciplines: BB, CH, ES, GE, or PH.
7. Must include exactly one of BUS 2060 or ACC 2101, and exactly one of BUS 2070 or FIN 2200, or their equivalents.

ACTUARIAL MATHEMATICS MAJOR PROGRAM CHART

<table>
<thead>
<tr>
<th>UNIVERSITY REQUIREMENTS</th>
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<tbody>
<tr>
<td>Minimum Academic Credit</td>
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<td>Residency</td>
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<td>Humanities and Arts</td>
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<td>Interactive Qualifying Project</td>
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<td>Major Qualifying Project</td>
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<td>Social Science</td>
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<td>Physical Education</td>
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FOUNDATION COURSES

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<th>INTRODUCTORY COURSES</th>
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<tbody>
<tr>
<td>MA 1021-1024</td>
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<td>MA 1020-1120</td>
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<td>MA 1033-1034</td>
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<td>MA 2210</td>
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<td>MA 2251</td>
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<tr>
<td>MA 2611</td>
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<thead>
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<th>TRANSITION COURSES (2/3 Unit Required)</th>
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<tbody>
<tr>
<td>MA 2073</td>
</tr>
<tr>
<td>MA 2271*</td>
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<td>MA 2273*</td>
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<td>MA 2431</td>
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<td>MA 2631</td>
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<table>
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<th>CORE COURSES (4/3 Unit Required)</th>
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<td>Both MA 3831 and MA 3832</td>
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OTHER MA COURSES TO ATTAIN TOTAL OF 6 UNITS:

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<table>
<thead>
<tr>
<th>OPERATIONS RESEARCH</th>
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<tr>
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<table>
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<th>Basic Science (2/3 Unit Required)</th>
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<th>Computer Science (2/3 Unit Required)</th>
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<th>School of Business (4/3 Unit Required)</th>
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<td>OIE 3510</td>
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</table>

* Category II courses, offered in alternating years.
Students interested in pursuing a degree in Actuarial Mathematics should contact Professor Abraham, the Coordinator of the Actuarial Mathematics Program, as soon as possible.

**MINOR IN STATISTICS**

Statistical methods are widely used in science, engineering, business, and industry. The Statistics Minor is appropriate for all WPI students with interests in experimental design, data analysis, or statistical modeling. The minor is designed to enable a student to properly design studies and analyze the resulting data, and to evaluate statistical methods used in their field of study. Students should discuss course selections for the minor in advance with a statistics faculty member, who serves as the Minor Advisor. The student must complete the Statistics Minor Program Planning and Approval Form, and have it signed by the Minor Advisor. Students are encouraged to do this as early as possible, but it must be done prior to starting the Capstone. The statistics minor consists of completion of at least 2 units of work, which must consist of:

1. At least 5/3 units of coursework, which must be drawn from the following lists of Foundation and Upper-Level Courses, and which must include successful completion of at least 2/3 units from each list:

   **Courses for Statistics Minor (5/3 Unit Required)**

   **Foundation Courses (2/3 Unit Required)**
   - MA 2073 Matrices and Linear Algebra II
   - MA 2611 Applied Statistics I
   - MA 2612 Applied Statistics II
   - MA 2631 Probability, 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 a Statistics faculty member. The Capstone must be approved in advance by having the Capstone instructor sign the Statistics Minor Program Planning and Approval Form. After completion of the Capstone Experience, the Statistics Minor Program Planning and Approval Form is submitted to the Mathematical Sciences Program Review Chair for final approval.

For information about the Statistics Minor, see any of the statistics faculty: Professors Joseph D. Petruccelli, Balgobin Nandram, or Zheyang Wu.

**MINOR IN MATHEMATICS**

The Minor in Mathematics consists of successful completion of at least 2 units of academic activities in mathematical sciences. Students should discuss course selections for the minor in advance with a member of the mathematical sciences faculty who will serve as the Minor Advisor. The student must complete the Mathematics Minor Program Planning and Approval Form and have it signed by the Minor Advisor. Students are encouraged to do this as early as possible, but it must be done prior to starting the Capstone. The following requirements must be satisfied:

1. At least 5/3 units must be coursework in the Mathematical Sciences Department at the 2000 level or above, of which at least 2/3 units must be upper-level courses, i.e. 3000-level, 4000-level, or graduate mathematics courses. Courses selected at the 2000 level, if any, must include at least one of the following courses:
   - MA 2073 Matrices and Linear Algebra II
   - MA 2251 Vector and Tensor Calculus
   - MA 2271 Graph Theory
   - MA 2273 Combinatorics
   - MA 2431 Mathematical Modeling with Ordinary Differential Equations
   - MA 2631 Probability

2. The final 1/3 unit Capstone Experience: The experience may be satisfied by certain 3000-level, 4000-level or graduate courses offered by the department or by a suitable independent study with a Mathematical Sciences faculty member. The Capstone must be approved in advance by having the Capstone instructor sign the Mathematics Minor Planning and Approval Form. After completion of the Capstone Experience, the Mathematics Minor Program Planning and Approval Form is submitted to the Mathematical Sciences Program Review Chair for final approval.

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

J. YAGOGBI, HEAD


ASSISTANT PROFESSORS: R. Cowlagi, S. Im, Y. Liu, C. Onal, P. Rao, Y. Wang


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 sensitivity 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.

STUDENT OUTCOMES

Graduating students should demonstrate that they attained 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 life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

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 or higher.
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 can be partially or fully accomplished by completing a Major Qualifying Project which integrates the past course work and involves significant engineering design. At the time of registration for the MQP, the project advisor will determine whether the MQP will meet the Capstone Design requirement or not. If not, the advisor will identify an additional 1/3 unit of course work in the area of design (ME 4320, ME 4429, or ME 4810) to be taken in order to meet the ABET Capstone Design requirement.
**MECHANICAL ENGINEERING DEPARTMENT CONCENTRATIONS**

**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.

**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

**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 4821 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 (HOFFMAN)**
Courses are available to support development of student interest in the design, analysis, and optimization of an assembly of components which produce a machine. Computer-based techniques are widely used in support of these activities.

Typical MQP topics are: optimum design of mechanical elements, stress analysis of machine components, evaluation and design of industrial machine components and systems, robotics, and computer-aided design and synthesis.

**Mechanical Design**
2 Required
- ME 3310 Kinematics of Mechanisms
- ME 3320 Design of Machine Elements
Select 4
- ES 1310 Computer-Aided Design
- ES 3323 Advanced Computer-Aided Design
- ME 2300 Introduction to Engineering Design
- ME 3311 Dynamics of Mechanisms and Machines
- ME 3506 Rehabilitation Engineering
- ME 4320 Advanced Engineering Design
- ME/RBE 4322 Modeling and Analysis of Mechatronic Systems
- ME 4810 Automotive Materials and Process Design
- ME/RBE 4815 Industrial Robotics
* Plus Mechanical Design MQP

**ROBOTICS (FISCHER)**
Students select courses to give them a solid foundation in the various aspects of robotics, including kinematics and actuators, sensors, and control and computing. In addition to relevant mechanical engineering courses, students can select courses from electrical engineering and computer science.
Typical MQP topics include designing of robots and robotic components, including mobile ground robots, aerial robots and underwater robots, automatic assembly and industrial robotics applications, and development of software and control algorithms for individual robots and robotic swarms.

**Robotics**

3 Required

- RBE 2001 Unified Robotics I
- ES 3011 Control Engineering I or ME 3310 Kinematics of Mechanisms
- ME/RBE 4322 Modeling and Analysis of Mechatronic Systems or ME/RBE 4815 Industrial Robotics

Select 3

- CS 2102 Object-Oriented Design Concepts
- CS 2301 Systems Programming for Non-Majors or CS 2303 Systems Programming Concepts
- CS 3733 Software Engineering
- CS 4341 Introduction to Artificial Intelligence
- ECE 2049 Embedded Computing in Engineering Design
- ECE 2311 Continuous-Time Signal and System Analysis
- ECE 2312 Discrete-Time Signal and System Analysis
- ECE 4703 Real-Time Digital Signal Processing
- ES 3011 Control Engineering I (If not selected above)
- ES 3323 Advanced Computer-aided Design
- ME 3310 Kinematics of Mechanisms (If not selected above)
- ME/RBE 4815 Industrial Robotics (If not selected above)
- RBE 2002 Unified Robotics II: Sensing
- RBE 3001 Unified Robotics III: Manipulation
- RBE 3002 Unified Robotics IV: Navigation

*Plus Robotics MQP*

*Others courses with approval from the ME Undergraduate Committee.

**THERMAL-FLUID ENGINEERING (YAGOOBI)**

Students study the theoretical and empirical bases of thermodynamics, heat transfer, mass transfer, and fluid flow, as well as the application of these fundamental engineering sciences to energy conversion, environmental control, and vehicular systems.

Typical MQPs include: biological fluid mechanics, laminar/turbulent separation, lifting bodies, heat pipes, electronic component cooling, power cycles, fluid component analysis and design, and energy storage.

**Thermal-Fluid Engineering**

3 Required

- ME/AE 3410 Compressible Fluid Dynamics
- ME/AE 3602 Incompressible Fluid Dynamics
- ME 4429 Thermodynamic Applications
- ME/AE 4710 Gas Turbines for Propulsion and Power Generation

Select 3

- ES 3002 Mass Transfer
- ME 3501 Continuum Mechanics
- ME 4429 Thermodynamic Applications
- ME 4430 Integrated Thermochemical Design and Analysis
- ME/BME 4606 Biofluids
- ME/AE 4710 Gas Turbines for Propulsion and Power Generation

*Plus Thermal-Fluids related MQP*

**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 212.

**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.

**MINOR IN MANUFACTURING ENGINEERING**

A minor in Manufacturing Engineering gives students from a variety of majors the opportunity to strengthen their academic preparation and attractiveness to industry, while better preparing them to solve many of the problems that will challenge them in their careers. Most engineers are involved directly or indirectly with manufacturing or manufacturing principles.

Manufacturing expertise is essential to all industrialized, developing and even post industrialized societies. The objective of the minor in manufacturing will be to give the students a solid understanding of the principles of production, processing, manufacturability, and quality that can be applied to a wide variety of products, including non-traditional products, such as software, service and information.

The minor requires the completion of 2 units of work as follows.

1. 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

2. 2/3 unit of electives, selected from the following list of courses:
   - any of the courses above, in I., can count if the other three are completed.
   - BUS 3020 Achieving Effective Operations
   - CS 4032/MA 3257 Numerical Methods for Linear and Nonlinear Systems
   - CS 4341 Introduction to Artificial Intelligence
   - ES 3323 Advanced Computer Aided Design
   - ME 3310 Kinematics of Mechanisms
   - ME/RBE 4815 Industrial Robotics
   - ME 4821 Plastics
   - OIE 3420 Quality Planning, Design and Control
STUDENTS EARNING A B.S. DEGREE IN MECHANICAL ENGINEERING MUST COMPLETE 15 UNITS OF STUDY, DISTRIBUTED AS FOLLOWS:

<table>
<thead>
<tr>
<th>4 UNITS OF NON-TECHNICAL ACTIVITIES</th>
<th>2 UNITS HUMANITIES AND ARTS</th>
<th>1 UNIT INTERACTIVE QUALIFYING (IQP) PROJECT</th>
<th>2/3 UNIT SOCIAL SCIENCE</th>
<th>1/3 UNIT PHYSICAL EDUCATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 UNIT FREE ELECTIVE</td>
<td>See WPI Requirements</td>
<td>See WPI Requirements</td>
<td>See WPI Requirements</td>
<td>See WPI Requirements</td>
</tr>
</tbody>
</table>

1 UNIT FREE ELECTIVE

<table>
<thead>
<tr>
<th>4 UNITS OF MATHEMATICS (MA) AND BASIC SCIENCE (BB, CH, GE 2341, PH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/3 Units</td>
</tr>
<tr>
<td>Student Selected Courses from the General Category of Mathematics</td>
</tr>
<tr>
<td>and/or Basic Science</td>
</tr>
</tbody>
</table>

5/3 Units
Differential & Integral Calculus and Ordinary Differential Equations

<table>
<thead>
<tr>
<th>3/3 Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Chemistry and Two Physics, OR One Physics and Two Chemistry</td>
</tr>
</tbody>
</table>

6 UNITS OF MECHANICAL ENGINEERING (Notes 1 & 2)

<table>
<thead>
<tr>
<th>MECHANICAL SYSTEMS</th>
<th>THERMAL SYSTEMS</th>
<th>OTHER COURSES</th>
<th>MAJOR QUALIFYING PROJECT (MQP)</th>
<th>ELECTIVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES 2501</td>
<td>ES 3001</td>
<td>ES 2001</td>
<td>ME 4429</td>
<td>At least one unit must be chosen in ME courses at the 4000-level or higher, or FPE 520, 521, 553.</td>
</tr>
<tr>
<td>ES 2502</td>
<td>ES 3004</td>
<td>ECE 2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ES 2503</td>
<td>ES 3003</td>
<td>ME 3901</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

Note 2: Elective courses from other engineering disciplines may also be selected at the 2000, 3000 or 4000 levels.

Note 3: ES 3001 may be replaced by CH 3510 or PH Thermodynamics. If CH or PH is used to cover thermodynamics, this course counts as a science; another engineering elective is then required.

Note 4: ECE 2010 or any ECE course other than ECE 1799.
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

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 11).

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).
MILITARY SCIENCE

MAJ J. R. LaValley, Head
Professor: MAJ J. R. LaValley
Assistant Professors: CPT K. Carney, MAJ F. J. Escobar, LTC F. Pagaduan
Instructors: SFC T. Blanchard, D. Gill, MSG J. Torrico

MISSION STATEMENT
The Military Science and Leadership Program (Army ROTC) is a premiere leadership and management program offered by WPI. Open to all students within the Worcester Consortium, the program is designed to teach valuable leadership skills and managerial traits that will prepare students for careers in the private and public sectors. Students partake in this hands-on experience that integrates traditional coursework with innovative challenging training. They develop strong decision-making and organizational management skills, team-building and interpersonal skills, as well as learn time and stress management techniques.

OBJECTIVES AND OUTCOMES
Students that participate in Army ROTC while pursuing their undergraduate and graduate studies are extremely marketable and highly sought after for their distinctive leadership capabilities. As technology transforms organizations, the desire for multi-faceted leaders has increased; the WPI Army ROTC prepares adaptable leaders for the future.

PROGRAM DESCRIPTION(S)
The Military Science and Leadership program is intended to be a four-year program that encourages personal growth and development.

MILITARY SCIENCE COURSE FLOW CHART

FRESHMAN
WPI COURSE STUDY

SOPHOMORE
WPI COURSE STUDY

JUNIOR
WPI COURSE STUDY

SENIOR
WPI COURSE STUDY

WPI DEGREE & U.S. ARMY COMMISSION

ML I
ML 1011
ML 1012
ML 1021
ML 1022
BASIC COURSE

ML II
ML 2011
ML 2012
ML 2021
ML 2022
LEADERSHIP TRAINING COURSE
ML 2091
ADVANCED COURSE

ML III
ML 3011
ML 3012
ML 3021
ML 3022
LEADERSHIP DEVELOPMENT AND ASSESSMENT COURSE
ML 3023

ML IV
ML 4011
ML 4012
ML 4023
ML 4024

(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.
BASIC COURSE
The first two years make up the Basic Course, which serves as the foundation to the program. During the Basic Course, the curriculum focuses on aspects of leadership, team-building, and communication skills. Students participate in adventure training, such as orienteering, rappelling, and paintball that puts their classroom learning to practice.

Students may participate in the first two years of the program commitment-free. Students awarded full-tuition scholarships or participate in the Advanced Course do incur a service obligation and may serve in the Army either full-time or part-time.

ADVANCED COURSE
The Advanced Course is a more intensive leadership program that is taken during the Junior and Senior years or during two years of graduate studies. The curriculum continues to concentrate on problem-solving and building teams, but also introduces military tactics and ethics.

Students interested in earning a commission as an Army Officer are required to enroll in the Advanced Course and attend the Cadet Leadership Course (CLC). CLC 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 an Army ROTC Scholarship receive a monthly stipend and $1,200 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.

3. Approved courses not offered at WPI; advance approval by the Physical Education Department is necessary so students are encouraged to contact the department directly in advance to review. No retroactive credit will be awarded if failure to receive advance approval.

4. Participation in certain ROTC programs may entitle students to a receive PE credit. Students in ROTC programs should review in advance with their respective commanders.

GENERAL PHYSICAL EDUCATION COURSES (PE 1000 SERIES)
This series is offered to provide a variety of courses in the more traditional sport-based area of physical education. These courses can serve the beginner to the more experienced in each activity area. PE 1000 series courses meet twice a week (generally between 8am-5pm) at predetermined times with attendance and participation major factors in a student's final grade.

HEALTHY ALTERNATIVE PHYSICAL EDUCATION COURSES (PE 1099)
These PE courses are offered to provide a variety of wellness, dance and healthy alternatives to traditional PE sport-based classes. These classes are subject to change on a yearly basis in order to provide flexibility in the PE offerings based upon the latest trends in wellness and dance. The focus of these classes is more on individual fitness, wellness and education, with instruction provided to all students in the classes.

THE CLUB SPORTS PROGRAM (PE 1200-SERIES)
The club sports program involves activities in various sports and wellness that are organized and recognized by the Student Government Association as Class II organizations and open to any undergraduate student (more information regarding Club Sports can be found at wpi.edu/+techsync). Students who are properly registered in advance for the club activity in their interest area and who meet the established criteria for participation by the club as well as by PERA department policy, may be eligible for PE course credit. Practice and/or competition times will vary but are generally in the evenings and weekends. Participating students may incur additional fees for equipment, travel, and/or uniforms.

PHYSICAL EDUCATION, RECREATION, AND ATHLETICS

D. L. HARMON, HEAD

REQUIREMENTS
Qualification in physical education shall be established by completing 1/3 unit of course work. Students are strongly urged to complete this graduation requirement in their first two years of residency at WPI. In addition to PE 1000-series course offerings, students may satisfy their PE requirement by the following:

1. WPI approved varsity athletic team participation (PE 2000-series). Student must be registered with instructor permission in advance of participation. No retroactive credit will be awarded if failure to register.

2. Club Sports (PE 1200-series). Students must be members of a PE approved club prior to becoming eligible for physical education credit and by meeting established department policies for credit. Students must be registered in advance of participation; no retroactive credit will be awarded if failure to register in advance. Additional fees for some clubs may apply.

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ATHLETIC PROGRAMS

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

WPI has excellent facilities and provides the best in protective equipment but, if an injury should occur, a team physician and full-time trainers are available, offering the latest treatment methods and facilities.

Practices are normally held daily, after 4 pm. Midweek contests involving travel are held to a minimum to avoid missing classes. Every effort is made to avoid conflicts with academic activities, and competitions are generally scheduled with schools with similar standards and objectives.

In recent years, teams and individuals have been sent to regional and national tournaments to allow them to compete at the highest possible level. All-America recognition has been attained recently in football, men’s soccer, track and field, and wrestling.

THE VARSITY ATHLETICS PROGRAM (PE 2000-SERIES)
The WPI varsity athletics program is a highly involved and competitive program offered in 18 intercollegiate sports. Participants in these activities are selected by the head coach and must have prior approval to register. Practices are held daily in the evenings with contests mid-week and weekends for a period of 18/19 weeks. Every effort is made to avoid conflicts with academic activities and competitions are generally scheduled against schools with similar standards and objectives.

PE 2001  Varsity Football Team
PE 2002  Varsity Men’s Soccer Team
PE 2003  Varsity Women’s Soccer Team
PE 2004  Varsity Field Hockey Team
PE 2005  Varsity Women’s Volleyball Team
PE 2006  Varsity Men’s & Women’s Cross Country Team
PE 2007  Varsity Wrestling Team
PE 2008  Varsity Men’s Basketball Team
PE 2009  Varsity Women’s Basketball Team
PE 2010  Varsity Men’s & Women’s Swim Team
PE 2011  Varsity Men’s & Women’s Indoor Track Team
PE 2012  Varsity Baseball Team
PE 2013  Varsity Softball Team
PE 2014  Varsity Men’s & Women’s Outdoor Track Team
PE 2015  Varsity Men’s Crew Team
PE 2016  Varsity Women’s Crew Team

PHYSICS

G. S. IANNACCIONE, HEAD
PROFESSORS: P. K. Aravind, G. D. J. Phillips, L. R. Ram-Mohan, A. A. Zozulya
ASSOCIATE PROFESSORS: N. A. Burnham, G. S. Iannacchione, R. S. Quimby
ASSISTANT PROFESSORS: D. L. Medich, I. Stroe, L.V. Titora, E. Tüzel, Q. Wen
ASSISTANT TEACHING PROFESSORS: B. Currier, F. A. Dick, S. Kadam, H. Kashuri, S. Sakar, S. Rodríguez
ASSISTANT SEARCH PROFESSOR: M. B. Popovic
AFFILIATED FACULTY: D. Lados (ME)

MISSION STATEMENT
The Physics Department provides education in physics to both undergraduate and graduate students and contributes to the growth of human knowledge through scholarly work.

PROGRAM EDUCATIONAL OBJECTIVES
The physics department educates students with a program characterized by curricular flexibility, student project work, and active involvement of students in their learning. Through a balanced, integrated curriculum stressing the widely applicable skills and knowledge of physics, we provide an education that is strong both in fundamentals and in applied knowledge, appropriate for immediate use in a variety of fields as well as graduate study and lifelong learning.

PROGRAM OUTCOMES
We expect that physics graduates:
1. Know, understand, and use a broad range of basic physical principles.
2. Have an understanding of appropriate mathematical methods, and an ability to apply them to physics.
3. Have demonstrated oral and written communications skills.
4. Can find, read, and critically evaluate selected original scientific literature.
5. Have an ability to learn independently.
6. Understand options for careers and further education, and have the necessary educational preparation to pursue those options.
7. Have acquired the broad education envisioned by the WPI Plan.
8. Are prepared for entry level careers in a variety of fields, and are aware of the technical, professional, and ethical components.
9. Are prepared for graduate study in physics and/or other fields.
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, science, engineering, computer science, and management (Note 3).</td>
<td>2</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. Either item 2 or 3 must include at least 1/3 unit in each of the six principal areas of physics: mechanics, experimental physics, electromagnetism, quantum mechanics, and thermal/statistical physics. This core distribution requirement is satisfied by successfully completing at least one course from each of the following areas: Mechanics (PH 2201 or PH 2202); Experimental Physics (PH 2651 or 2601); Electromagnetism (PH 2301 or PH 3301); Quantum Mechanics (PH 3401 or 3402); and Thermal/Statistical Physics (ES 3001, CH 3510, PH 2101, or PH 3206). Other courses or IS/Ps may satisfy one or more of these areas but must be approved by the department Undergraduate Curriculum Committee. For substitutions, the student must submit a petition with a substitution proposal prior to the activity and the activity outcome must be approved by a physics faculty who has taught in the particular area.

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 SERVICES</th>
<th>PHYSICS REQUIREMENTS</th>
<th>PHYSICS COURSE(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA 1021 Calculus I</td>
<td>PH 1110 Mechanics</td>
<td></td>
</tr>
<tr>
<td>MA 1022 Calculus II</td>
<td>PH 1120 Electricity and Magnetism</td>
<td></td>
</tr>
<tr>
<td>MA 1023 Calculus III</td>
<td>PH 1111 Mechanics</td>
<td></td>
</tr>
<tr>
<td>MA 1024 Calculus IV</td>
<td>PH 1121 Electricity and Magnetism</td>
<td></td>
</tr>
<tr>
<td>MA 1023 Calculus III</td>
<td>PH 1130 Modern Physics</td>
<td></td>
</tr>
<tr>
<td>MA 1024 Calculus IV</td>
<td>PH 1140 Oscillations and Waves</td>
<td></td>
</tr>
<tr>
<td>MA 2051 Differential Equations</td>
<td>PH 2202 Intermediate Mechanics II</td>
<td></td>
</tr>
<tr>
<td>MA 2071 Linear Algebra</td>
<td>PH 2651 Physics Laboratory</td>
<td></td>
</tr>
<tr>
<td>MA 2251 Vector/Tensor Calculus</td>
<td>PH 2301 Electromagnetic Fields I</td>
<td></td>
</tr>
<tr>
<td>MA 4451 Boundary Value Problems</td>
<td>PH 3301 Electromagnetic Theory</td>
<td></td>
</tr>
<tr>
<td>PH 1104 Quantum Mechanics I</td>
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</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

<table>
<thead>
<tr>
<th>PHYSICS SERVICES</th>
<th>PHYSICS REQUIREMENTS</th>
<th>PHYSICS COURSE(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH 3402</td>
<td>Quantum Mechanics II</td>
<td></td>
</tr>
<tr>
<td>PH 511</td>
<td>Classical Mechanics</td>
<td></td>
</tr>
<tr>
<td>PH (IS/P)</td>
<td>Selected Readings in Physics</td>
<td></td>
</tr>
</tbody>
</table>

Related Courses

<table>
<thead>
<tr>
<th>PHYSICS SERVICES</th>
<th>PHYSICS REQUIREMENTS</th>
<th>PHYSICS COURSE(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECE 2029</td>
<td>Introduction to Digital Circuit Design</td>
<td></td>
</tr>
<tr>
<td>ECE 2311</td>
<td>Continuous-Time Signal and System Analysis</td>
<td></td>
</tr>
<tr>
<td>ECE 2312</td>
<td>Discrete-Time Signal and System Analysis</td>
<td></td>
</tr>
<tr>
<td>ES 3011</td>
<td>Control Engineering I</td>
<td></td>
</tr>
<tr>
<td>MA 4291</td>
<td>Applicable Complex Variables</td>
<td></td>
</tr>
</tbody>
</table>

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PH 2510  Atomic Force Microscopy  
PH 3501  Relativity  
PH 3502  Solid State Physics  
PH 3503  Nuclear Physics  
PH 3504  Optics  
PH (IS/P)  Modern Optics  

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

**Related Courses**  
ECE 2029  Introduction to Digital Circuit Design  
ECE 2311  Continuous-Time Signal and System Analysis  
ECE 2312  Discrete-Time Signal and System Analysis  
ES 3011  Control Engineering I  
CS 1101  Introduction to Program Design  
CS 2011  Introduction to Computer Organization and Assembly Language  
CS 2301  Systems Programming for Non-Majors  
CS 4731  Computer Graphics  
MA 3457/CS 4033  Numerical Methods for Calculus and Differential Equations  
MA 4291  Applicable Complex Variables  
PH 3402  Quantum Mechanics II  
PH 3502  Solid State Physics  

3. Optics  
**Recommended Courses**  
PH 2501  Photonics  
PH 2502  Lasers  
PH 3504  Optics  

**Related Courses**  
AR/ID 3150  Light, Vision, and Understanding  
ECE 2311  Continuous-Time Signal and System Analysis  
ECE 2312  Discrete-Time Signal and System Analysis  
ES 3011  Control Engineering I  
MA 4291  Applicable Complex Variables  
PH 3402  Quantum Mechanics II  
PH 3502  Solid State Physics  

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

**Related Courses**  
ECE 2311  Continuous-Time Signal and System Analysis  
ECE 2312  Discrete-Time Signal and System Analysis  
ES 3011  Control Engineering I  
MA 4291  Applicable Complex Variables  
PH 3402  Quantum Mechanics II  
PH 3502  Solid State Physics  

5. Nuclear Science and Engineering  
**Recommended Courses**  
NSE 510  Introduction to Nuclear Science and Engineering  
NSE 520  Applied Nuclear Physics  
PH (ISP/P)  Nuclear Physics Applications  
PH 3503  Nuclear Physics  

6. Thermal Physics  
**Recommended Courses**  
PH 2101  Principles of Thermodynamics  
or ES 2001  Introduction to Thermodynamics  
or CH 3510  Chemical Thermodynamics  
ES 3004  Fluid Mechanics  
PH 3206  Statistical Physics  
PH (IS/P)  Selected Readings in Thermal Physics  

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

7. Biophysics  
**Recommended Courses**  
ES 3001  Introduction to Thermodynamics  
ME/BME 4504  Biomechanics  
ME/BME 4606  Biofluids  
PH 3206  Statistical Physics  
PH (IS/P)  Review of Biophysics  

**Related Courses**  
BB 2550  Cell Biology  
BME 2210  Biomechanical Signals, Instruments, and Measurements  
BME 2511  Introduction to Biomechanics and Biotransport  
CH 4110  Biochemistry I  
CH 4120  Biochemistry II  
CH 4160  Membrane Biophysics  
ES 3004  Fluid Mechanics  

**MINOR IN PHYSICS**  
The Physics Minor offers non-Physics majors the opportunity to broaden their understanding of both the principles of physics and the application of those principles to modern day engineering problems. In these times of rapid technological change, knowledge of fundamental principles is a key to adaptability in a changing workforce.  
Two units of coordinated physics activity are required for the Physics Minor, as follows (note that, in accordance with Institute policy, no more than 3/3 of these units may be double-counted toward other degree requirements):  

1. Any or all of the following four introductory courses:  
PH 1110 or PH 1111  
PH 1120 or PH 1121  
PH 1130  
PH 1140  

2. At least 2/3 unit of upper level physics courses (2000 level or higher), which may include 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):
Students who have taken the four course introductory sequence should have an adequate physics background for these courses; see, however, the individual course descriptions for the expected mathematical background. Other physics courses may be selected for the physics minor, but the recommended background for such courses often includes one or more of the courses listed above.

3. Capstone Experience

The capstone experience for the physics minor can be satisfied either by an independent study project (IS/P) arranged for this purpose, or by one of the upper level courses. If the second option is chosen, the student must discuss this with the instructor prior to the start of the course. In either case, documentation of the capstone experience will consist of a paper, prepared in consultation with the instructor or independent study project advisor, which incorporates and ties together concepts learned in the physics courses selected.

For more information, or assistance in selecting a minor advisor or an independent study advisor, see the Head of the Physics Department in Olin Hall 119.

Majors in Physics or Engineering Physics do not qualify for a Minor in Physics.

MINOR IN ASTROPHYSICS

For students of the sciences interested in the stars and seeking to acquire a minor expertise with a cosmic perspective, the Physics Department offers a Minor in Astrophysics. Candidates for the Minor complete two units of work, with one unit of Astrophysics courses, and one unit of recommended background courses consisting of: 1/3 unit of mechanics, 1/3 unit of electromagnetism and 1/3 unit of quantum mechanics.

Astrophysics Courses:
- Solar Systems: PH2540
- Space Environments: PH2550/AE2550
- Astrophysics: PH2520

Recommended Background Courses (choose one from each category):
- Mechanics: PH 1110/1111, PH 2201, PH 2202, PH 4201, or PH 511
- Electromagnetism: PH 1120/1121, PH 2301, PH 3301, or PH 533
- Quantum Mechanics: PH 1130, PH 3401, PH 3402, or PH 514

Candidates also complete an Astrophysics Minor Project either as part of one of the astrophysics courses or as a separate IS/P. The project consists of: a) selecting an astrophysical topic of interest, b) posing a relevant question and performing in-depth analysis and investigation, and c) writing a paper, all in consultation with the instructor advising the project.

Students majoring in Physics or in Applied Physics may not do a Minor in Astrophysics.

Students complete the “Application for a Minor in Astrophysics” and present it to the Head of the Physics Department. The Application is available in the Physics Department Office. The Head of the Physics Department will be responsible for the review and approval of all requests for the Minor. WPI policy requires that no more than one unit of course work be double counted toward other degree requirements.

SPECIAL PROGRAMS

MINOR IN NANOSCIENCE

Important to nanoscience are the studies of the structure and function of molecules, and the quantum and atomic properties of matter. Nanoscientists investigate fundamental aspects of the behavior of molecules, materials, devices, and living matter at length scales smaller than the wavelength of visible light. Synthesizing knowledge across disciplines greatly enhances progress in understanding nanoscale systems. A Minor in Nanoscience will benefit students who wish to enhance their disciplinary major with an additional degree designation in the area of Nanoscience.

The Minor in Nanoscience requires the completion of at least two units of course work in the topical areas described below. Students planning the minor should contact Professor Burnham in the Physics Department.

1. Structure of Molecules. At least one course (1/3 unit) in organic, inorganic, or physical chemistry.

2. Function of Molecules. At least one course (1/3 unit) selected from the following list:
   - BB 1035: Introduction to Biotechnology
   - BB 2550: Cell Biology
   - BB 2920: Genetics

3. Quantum Properties of Matter. At least one course (1/3 unit) selected from the following list:
   - CH 3530: Quantum Chemistry
   - PH 1130: Modern Physics
   - PH 2501 or 2502: Photonics or Lasers
   - PH 3401 or 3402: Quantum Mechanics

4. Atomic Properties of Matter. At least one course (1/3 unit) selected from the following list:
   - ES 2001: Introduction to Material Science
   - ME 4875: Introduction to Nanomaterials and Nanotechnology
   - PH 3502: Solid State Physics

5. Nanoscale Fabrication and Characterization. (No minimum number of required courses.)
   - CHE/ME 2301: Nanobiotechnology Laboratory Experience
   - PH 2510: Atomic Force Microscopy

6. Interdisciplinary Capstone Experience in Nanoscience. (1/3 unit).

   The capstone experience for the nanoscience minor can be satisfied either by i) an independent study arranged for this purpose as the sixth course in the sequence, or ii) a small project during an existing course, also as the sixth course in the sequence. If the second option is chosen, the student must arrange an interdisciplinary capstone experience with the instructor prior to the start of the course, and the...
instructor must agree to advise it. In either case, documentation of the capstone is required, prepared in consultation with the independent study advisor or instructor, which incorporates and ties together concepts learned in the nanoscience courses selected. After successful completion of the capstone, the instructor shall notify the student, Professor Burnham in the Physics Department, and the Registrar.

NOTES

a. In keeping with Institute-wide policy for minors, up to three courses may be double-counted for degree requirements (at most 1/3 unit of IQP), no course may be triple-counted, and the capstone experience must be done at the end of the sequence. The Major Qualifying Project (MQP) may not be counted toward activity for Minors.

b. Other courses, including graduate courses, may be used to satisfy the four topic areas with the approval of the Nanoscience Minor Committee.

c. A list of faculty who are willing to advise Nanoscience Capstones or ISPs is given at the bottom of http://www.wpi.edu/academics/Depts/Physics/AFM/academic.html.

PRE-LAW PROGRAMS

ADVISOR: K. RISSMILLER

Law schools do not require that undergraduates complete any particular course of study. Thus, students who complete degrees in engineering and science may wish to consider careers in law. Undergraduates interested in attending law school are encouraged to choose from among the many courses offered which explore legal topics. For those with greater interest, WPI offers a Minor in Law and Technology described on page 118. 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 administration 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.

To see the Law and Technology Minor, go to page 118.

FIVE-YEAR DUAL BACHELOR/M.S. IN MANAGEMENT (MSMG)

The combination of a technical undergraduate degree and a graduate degree in business has been cited by many experts as the ideal educational preparation for a career in private industry. For that reason, the School of Business offers the opportunity for obtaining dual degrees - the Bachelor of Science (BS) and the Master of Science in Management (MSMG). Moreover, the MSMG provides a compelling pathway to the Master of Business Administration (MBA) while recognizing the value of work experience. Upon receiving your MSMG from WPI, and after a minimum of 2 years of work experience and within 6 years of completing your MSMG, you may apply to return to WPI, either full-time or part-time, to earn your MBA in just 7 additional courses, including the hallmark project experience of WPI.

The dual BS/MS in Management program can be completed within five years, however, the program is demanding, and curriculum planning with the student’s advisor and the School of Business should start by the beginning of the student's third year at WPI. Only registered WPI undergraduates may enter the dual degree program. A separate and complete application to the MSMG program must be submitted during the student’s third year of undergraduate study. Admission to the dual BS/MS program is determined by the School of Business.

A student in the dual BS/MSMG program continues to be registered as an undergraduate until the bachelor's degree is awarded. BS/MSMG students must satisfy all requirements for the bachelor's degree, including distribution and project requirements, as well as all MSMG requirements.

MSMG students must complete the following seven required courses:

- BUS 500 Business Law, Ethics, and Social Responsibility
- FIN 500 Financial Information and Management
- FIN 501 Economics for Managers
- MIS 500 Innovating with Information Systems
- MKT 500 Marketing Management
- OBC 500 Group and Interpersonal Dynamics in Complex Organizations
- OIE 500 Analyzing and Designing Operations to Create Value

Students then select 3 electives, 2 of which must be from the School of Business.

A student in the dual BS/MSMG may, with prior approval, apply the equivalent of a maximum of 12 graduate credits from the same courses toward both the bachelor's and master's degrees. Students must be admitted into the dual BS/MSMG prior to taking graduate-level business courses.

The School of Business 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 School of Business, and must be filed with the registrar before the student may be matriculated in the dual BS/MSMG program.
PRE-MEDICAL, PRE-DENTAL, PRE-OPTOMETRY, AND PRE-VETERINARY PROGRAMS

ADVISOR: A. CARLSEN-BRYAN

Students at WPI who wish to pursue careers in the health professions should, in consultation with their academic advisors, plan their academic programs to include courses in biology, general and organic chemistry, biochemistry, and physics including laboratory experiences. 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. 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
- Biochemistry 1 course
- Biology* 3 courses
- Physics* 3 courses

* These courses must include laboratory components.

Students should consult catalogs of the individual health professions schools for specific requirements. Pre-med students are encouraged to consult with the Medical School Admissions Requirement (MSAR) resource.

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’s Cummings 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 professional 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 and the committee packet process as well as to plan for a letter of recommendation from the pre-health committee to support their application. These meetings should happen during your first year as an undergraduate student. The committee packet is released every January and is due alongside all letters of recommendations at the end of March of the year that students are applying.

TEACHER LICENSING

ADVISOR: J. GOULET

WPI students wishing to receive an Initial License as a middle or high school teacher in Massachusetts in the areas of Biology, Chemistry, Mathematics or Physics may do so by joining WPI’s Teacher Preparation program. Along with completing a major of the student’s choice, participants use their Social Sciences requirement to take Psychology of Education (PSY2401) and Cross-Cultural Psychology (PSY2406) as well as two electives for Teaching Methods (ID3100) and Sheltered English Immersion (ID320X). Additionally participants complete an off campus teaching practicum, typically done as their IQP, and pass the state MTEL teaching test. Certain content courses are required depending on the desired area however this requirement is typically covered by courses in the student’s major.

Licenses teachers in STEM fields (Bio, Chem, Math, Physics) are in continual high demand across the United States. By joining this program, a student is able to pursue their content area of choice as well as make a difference in the lives of their students. Students wishing to discuss or pursue this opportunity should see Professor John Goulet (MA) and/or see wpi.edu/+teach.

ROBOTICS ENGINEERING

DIRECTOR: M. A. GENNERT

ASSOCIATE DIRECTORS: T. PADOR, K. STAFFORD

ASSOCIATED FACULTY: H. K. Ault (ME), Scott Barton (HUA), Dmitry Berenson (CS), S. H. Chernova (CS), M. J. Ciaraldi (CS), R. Cowlingi (ME), D. Cyganski (ECE), R. J. Duckworth ECE), A. E. Emanuel (ECE), G. Fischer (ME), C. Furlong-Vazquez (ME), M. A. Gennert (CS), A. H. Hoffman (ME), R. W. Lindeman (CS), F. J. Looff (ECE), W. R. Michalsen (ECE), C. Onal (ME), T. Padir (ECE), M.B. Popovic (PH), C. B. Putnam (CS), C. Rich (CS), Y. Rong (ME), L. E. Schachterle (HUA), C. L. Sidner (CS), J. Skorinko (SSPS), K. A. Stafford (ME), E. Torres-Jara (CS)

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 life-long learning,
- a knowledge of contemporary issues, and
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

**NOTES:**
1. Must include Differential and Integral Calculus, Differential Equations, Linear Algebra, and Probability.
2. Must include at least 2/3 units in Physics.
3. Must include at least 1/3 unit of Social Implications of Technology (CS 3043, GOV 2302, GOV/ID 2314). If GOV 2302, or GOV/ID 2314 are double-counted as meeting the Social Science Requirement and the Social Implications Requirement, then the Distribution Requirements total 10 units, otherwise the Distribution Requirements total 10 1/3 units.
4. Must include at least 5/3 units in Robotics Engineering, including RBE 2001, RBE 2002, RBE 3001, and RBE 3002, or equivalent.
5. Must include at least 1 unit in Computer Science, including Object-Oriented Programming and Software Engineering.
6. Must include at least 2/3 units in Electrical and Computer Engineering, including Embedded Systems.
7. Must include at least 1/3 unit in Statics and 1/3 unit in Controls.
8. Must include at least 1 unit of Engineering Science and Design Electives, of which at least 2/3 unit must be at the 4000-level or higher.
9. The MQP must be a Capstone Design Experience in Robotics Engineering.

**MAJOR QUALIFYING PROJECTS**
Robotics Engineering MQPs are capstone design activities that span a wide range of topics from autonomous ground/air/underwater vehicles to swarm robotics to human-robot interaction, with applications in surgery, inspection, manufacturing, security, and entertainment, to name but a few. All RBE MQPs must go through the breadth of the design experience, including conceptualization, requirements, design, implementation, evaluation, and documentation. Projects also address societal issues, including professional responsibility, ethical and environmental considerations, sustainability, aesthetics, and safety. RBE MQPs may be sponsored by industry, including the Lincoln Lab and Silicon Valley project centers, develop from faculty research, or be initiated by students. Please see the Robotics Engineering website [http://robotics.wpi.edu/](http://robotics.wpi.edu/) for information on current projects.

**ADDITIONAL ADVICE**
For additional advice about course selections, including elective choices, students should consult with their academic advisor.

**MINOR IN ROBOTICS ENGINEERING**
The Minor in Robotics Engineering consists of 2 units of work distributed as follows:

1. 1/3 unit CS selected from CS 2102, CS 2223, CS 2301, CS 2303, CS 3733.
2. 1/3 unit ECE selected from ECE 2010, ECE 2019, ECE 2029, ECE 2049, ECE 2311.
3. 1/3 unit ME/ES selected from ES 2501, ES 2503, ES 3011, ME 3310.
4. 2/3 units from RBE 1001, RBE 2001, RBE 2002.
5. A 1/3 unit capstone experience through an RBE course at 3000-level or above.

No more than 1 unit of work may overlap the major. Students considering a Robotics Engineering Minor should consult with the RBE Undergraduate Program Committee.
SOCIAL SCIENCE AND POLICY STUDIES

J. K. DOYLE, HEAD; R. KRUEGER, ASSOCIATE HEAD

PROFESSORS: S. Landau, K. Saeed
ASSISTANT PROFESSORS: I. Arroyo, L. Elgert, M. John, A. Smith
ASSISTANT TEACHING PROFESSOR: P. Stapleton, E. Stoddard
ADJUNCT FACULTY: G. Heaton, D. Kantarelis, J. Morecroft, K. Warren, J. Yee

MISSION STATEMENT
Recognizing the increasingly important role that the social sciences play in our complex, technological world, the Department of Social Science and Policy Studies offers cutting edge educational and research programs in a variety of disciplines, including economics, environmental and sustainability studies, government/law, learning sciences, psychology, sociology, and system dynamics. Our programs, ranging from undergraduate general education in the social sciences to interdisciplinary Ph.D. degrees, are distinguished by their emphasis on behavioral science, commitment to project-based learning, and use of state-of-the-art methods and technologies. We are committed to helping students at all levels to think critically about important societal problems and to identify effective solutions.

PROGRAMS
The SSPS Department supports general education in the social sciences through the university-wide Social Science Requirement. The Department offers B.S. degrees and minors in Economic Science, Psychological Science, Society, Technology & Policy, and System Dynamics. The Department also serves as the home for the Pre-Law program and Law & Technology Minor and is the lead department for the interdisciplinary B.A. program in Environmental and Sustainability Studies. Given the diversity of offerings in the department, each program has a unique set of goals and outcomes.

For additional advice about course selections, students should consult with their academic advisor. Detailed curriculum guidelines for each program as well as recommendations for completing the Social Science Requirement are available on the Social Science and Policy Studies Department Web site (www.wpi.edu/academics/ssps.html).

COURSE AREAS
The SSPS Department covers many of the traditional social science disciplines. Courses with the following prefixes are found in the Department:

ECON  Economics
ENV  Environmental and Sustainability Studies
GOV  Political Science, Government, and Law
PSY  Psychology
SD  System Dynamics
SOC  Sociology
SS  General Social Science
STS  Society-Technology Studies

DOUBLE MAJOR IN SOCIAL SCIENCE AND POLICY STUDIES
Any of the major programs offered by the SSPS Department may be taken as part of a double major in which the student majors in an area of science, engineering or management as well as social science. To obtain a double major, the student must satisfy all of the degree requirements of both majors, including the MQP and Distribution requirements. However, the MQP in the social science discipline may double count as the IQP, provided that the combined project meets the goals of both. It must be interactive in nature involving an aspect of technology as well as an application of social science knowledge and analytical techniques. Thus double majors for whom one of the majors is in the social sciences requires only two projects, not three. The decision to pursue the social science double major should be made fairly early in the student's academic career, certainly early enough to ensure the selection of an appropriate IQP/MQP.

UNDERGRADUATE RESEARCH OPPORTUNITIES
SSPS faculty are actively engaged in experimental research in a variety of applied social science areas, with particular strength in economics, learning sciences, psychology, and system dynamics. Undergraduates interested in gaining experience in behavioral research should contact one or more of the following faculty about opportunities to work in social science research laboratories:

- Advanced Learning Technologies (Prof. Arroyo)
- Experimental Economics Lab (Prof. Smith)
- Social Psychology Inquiry Lab (Prof. Skorinko)

ECONOMIC SCIENCE PROGRAM
Economists study how both individuals and institutions make decisions about the utilization and distribution of resources. They also monitor economic data and analyze trends, examine the impact of economic policies and behaviors, and help formulate new policies and anticipate their effects. WPI’s economic science major emphasizes the use of computational modeling and experimentation to achieve these goals.

PROGRAM OUTCOMES
In addition to fulfilling WPI’s university-wide undergraduate learning outcomes, economic science majors will demonstrate:

1. Command of macro-economic and micro-economic theory.
2. Awareness of economic history and the evolution of thought in economics.
3. Skills in key economic modeling techniques, including econometrics and system dynamics.
4. Skills using data collected in a variety of ways, including surveys, experiments and through observation in the field.
5. Skill in mathematics as required to approach and solve economic problems.
7. Knowledge of key economic institutions that make policy and influence economic practice.
8. Ability to understand current economic issues in light of economic theories.

9. Ability to approach and solve a practical problem like an economist.

10. Deep understanding of fundamental economic problems in a specific area of application.

Program Distribution Requirements for the Economic Science Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in economics, social science, basic science, and mathematics as follows:

<table>
<thead>
<tr>
<th>ECONOMIC SCIENCE 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, BUS 2060. May include other relevant business courses as approved by the Departmental Program Review Committee.
3. Must include differential equations, integral calculus, and statistics.

CONCENTRATION AREAS AVAILABLE IN ECONOMIC SCIENCE

Economic Science majors may focus their studies by choosing a Concentration within one of the following two specific areas of Economics: Sustainable Economic Development and Computational Economics. These concentration areas reflect the growing importance of environmental issues and computational tools within the discipline of economics and are areas of strength in teaching and research in the social sciences at WPI. Concentrations within the Economics Science major comply with WPI’s requirements for concentrations. Students must complete an MQP and two units of integrated study in the area of their Concentration.

Sustainable Economic Development. The term sustainable economic development means choosing policies that balance environmental preservation and economic development so as to meet the needs of the present generation without seriously compromising the needs of future generations. The sustainable development concentration examines the economic, psychological, social, political, legal, and technical issues surrounding the creation of policies aimed at establishing sustainable economic systems at the local, national, and international levels.

1. 1 unit from the following list of courses in economic development:
   - ECON 2125 Development Economics
   - ECON 2117 Environmental Economics
   - CE 3070 Urban Environmental Planning
   - CE 3074 Environmental Analysis
   - HI 3333 Topics in American Technological Development

2. 1 unit from the following list of environmental courses in other social science disciplines, humanities, and biology, or additional courses from list 1:
   - BB 1002 Environmental Biology
   - BB 4150 Environmental Change: Problems and Approaches
   - ENV 1100 Introduction to Environmental Studies
   - ENV 2200 Environmental Studies in the Various Disciplines
   - ENV 2400 Environmental Problems and Human Behavior
   - GOV 2311 Legal Regulation of the Environment
   - GOV 2312 International Environmental Policy
   - PY 2717 Philosophy and the Environment

Computational Economics. Students in the computational economics concentration supplement their knowledge of traditional tools of economic analysis by studying modern computational techniques. Student projects may address problems of complex macroeconomic modeling, chaos, computational finance, design of automated Internet markets, and many more. This concentration draws on the expertise and talent of the faculty in various departments throughout the university.

1. 1 unit from the following list of courses in system dynamics:
   - SD 1510 Introduction to System Dynamics Modeling
   - SD 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:
   - CS 2022/MA2201 Discrete Mathematics
   - CS 4032/MA3257 Numerical Methods for Linear and Nonlinear Systems
   - CS 4033/MA3457 Numerical Methods for Calculus and Differential Equations
   - CS 4341 Introduction to Artificial Intelligence
   - ES 3011 Control Engineering I
   - OIE 3460 Simulation Modeling and Analysis
   - OIE 3510 Stochastic Models
   - MA 2210 Mathematical Methods in Decision Making
   - MA 2431 Mathematical Modeling with Ordinary Differential Equations
   - MA 3471 Advanced Ordinary Differential Equations
   - MA 4235 Mathematical Optimization
   - MA 4411 Numerical Analysis of Differential Equations

PSYCHOLOGICAL SCIENCE PROGRAM

Psychology is the study of the entire range of human experience, thought, and behavior, from infancy until death, from the most abnormal behavior to the most mundane, from the behavior of neurons to the actions of societies and nations. Psychologists employ a wide variety of methods to understand behavior and to discover how best to improve performance, including controlled experiments on human subjects. WPI’s major in psychological science emphasizes empirical research in the areas of social and cognitive psychology as well as practical applications to the classroom, the courtroom, and other settings.
### PROGRAM OUTCOMES
In addition to fulfilling WPI’s university-wide undergraduate learning outcomes, psychological science majors will demonstrate:

1. Familiarity with the major concepts, theoretical perspectives, empirical findings, and trends in psychology.
2. Understanding of and ability to apply basic research methods in psychology, including experimental design, data analysis, and interpretation.
3. Ability to apply psychological principles to personal, social, organizational, and societal issues, including developing insight into their own and others’ behavioral and mental processes.
4. Understanding of the relationships and interactions between psychology and other social science domains.
5. Ability to understand the role of and apply knowledge of psychological phenomena in other domains, such as business, computer science, or biology.
6. Ability to recognize, understand, and respect the complexity of sociocultural and international diversity.
7. Understanding of the ethics of human subjects research and the ability to apply that understanding in designing research or practices that do not violate ethical guidelines.
8. Knowledge of basic science and how it contributes to understanding human behavior.

[Adapted from the American Psychological Association Report on Undergraduate Psychology Learning Goals and Outcomes.]

### Program Distribution Requirements for the Psychological Science Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in psychological science, social science, basic science, and mathematics as follows:

<table>
<thead>
<tr>
<th>PSYCHOLOGICAL SCIENCE REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Psychological Science (Note 1)</td>
<td>3</td>
</tr>
<tr>
<td>2. Psychological Science and/or Related Courses (Note 2)</td>
<td>1</td>
</tr>
<tr>
<td>3. Other Social Science (Note 3)</td>
<td>1</td>
</tr>
<tr>
<td>4. Basic Science, Computer Science, and/or Engineering (Note 4)</td>
<td>5/3</td>
</tr>
<tr>
<td>5. Mathematics (Note 5)</td>
<td>4/3</td>
</tr>
<tr>
<td>6. Electives (Note 6)</td>
<td>1</td>
</tr>
<tr>
<td>7. MQP</td>
<td>1</td>
</tr>
</tbody>
</table>

**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.

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### SOCIETY, TECHNOLOGY, AND POLICY PROGRAM

Policy analysts apply an array of skills and techniques to evaluate the impacts of existing policies, both public and private, and to help formulate new policies to address societal needs. WPI’s major in society, technology, and policy focuses on the relationships between science-technology, society, government, and business. The program allows students to develop a strong interdisciplinary background in these areas and to learn the analytical tools and methods needed to apply this knowledge to important questions in such areas as environmental policy and regulation, science-technology policy, and internet policy.

### PROGRAM OUTCOMES
In addition to fulfilling WPI’s university-wide undergraduate learning outcomes, society, technology, and policy majors will demonstrate:

1. Ability to conduct public policy analysis, technology assessment, or social impact analysis.
2. Understanding of and ability to apply research methods in the social sciences.
3. Ability to communicate effectively the results of a social analysis with policy implications in speech and writing.
4. Understanding of the relationships between technology, policy, and the public interest in a democratic society.
5. Ability to integrate understanding of science and technology into thinking on the social implications of science and technology.
6. Ability to understand the impacts of government regulation on the future development of a technology or industry.
7. Literacy in the technological aspects of policy issues in the student’s area of concentration.
8. Ability to identify and appropriately consider ethical constraints during science and technology policy deliberations and decision-making.

### Program Distribution Requirements for the Society, Technology, and Policy Major

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in social science, basic science, and mathematics as follows:

<table>
<thead>
<tr>
<th>SOCIETY, TECHNOLOGY AND POLICY REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Social Science (Notes 1, 2)</td>
<td>4</td>
</tr>
<tr>
<td>2. Minimum Basic Science background</td>
<td>2/3</td>
</tr>
<tr>
<td>3. Minimum Mathematics background (Note 3)</td>
<td>1</td>
</tr>
<tr>
<td>4. Technical concentration (Note 4)</td>
<td>5/3</td>
</tr>
<tr>
<td>5. Electives (Note 5)</td>
<td>5/3</td>
</tr>
<tr>
<td>6. MQP</td>
<td>1</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Students must obtain approval of their proposed program from the Departmental Program Review Committee. Course distribution will focus on a disciplinary specialty and either policy analysis or a society-technology specialization such as Social Impact Analysis or Technology Assessment.
2. Relevant Humanities or Business courses approved by the Departmental Review Committee may be counted for a maximum of 2/3 of a unit in fulfilling the 4-unit requirement.
3. One course in calculus-based statistics is required.
4. A series of courses in one field of science, engineering, or business or a combination of courses approved by the departmental review committee which focus on issues to be developed in the MQP.
5. These courses are to be approved by the Departmental Review Committee and are meant to broaden the technical concentration and tie it to social concerns.

**SYSTEM DYNAMICS PROGRAM**

System dynamicists develop and test computer simulation models to analyze causal relationships in complex social, economic, and physical systems. The tools and techniques of system dynamics enable decision makers and policymakers to engage in long-term, big picture thinking that explores the structure and feedback relationships in complex systems and to anticipate the implications of their policies before implementing them. WPI’s system dynamics major provides a strong background in the tools and techniques of system dynamics modeling and the opportunity to apply this knowledge to develop policy solutions to complex social problems in a variety of application areas.

**PROGRAM OUTCOMES**

In addition to fulfilling WPI’s university-wide undergraduate learning outcomes, system dynamics majors will demonstrate:

1. Ability to recognize the dynamic patterns of behavior in real-world data.
2. Ability to formulate feedback hypotheses representing problems and understand the hypotheses’ logic.
3. Ability to translate feedback hypotheses into stock and flow models.
4. Ability to experiment with stock and flow models in order to establish their fidelity.
5. Ability to design experiments with a stock and flow model, implement them, and interpret their results, in order to arrive at effective solutions that address the defined problems of a system dynamics project.
6. Literacy in the technical aspects of problems in the student’s area of application.
7. Ability to communicate effectively the results of a system dynamics analysis in speech and writing.
8. An understanding of basic concepts in software programming and management science.
9. An understanding of how to apply scientific principles in system dynamics modeling.
10. Ability to develop, organize, manage, and successfully conduct a significant system dynamics project.
11. Ability to locate and integrate valid and appropriate information from multiple fields and perspectives for use in systems dynamics models.
12. An understanding of the endogenous causes of societal problems.
14. Ability to form and work effectively in groups involving system dynamics modelers, appropriate domain experts, and stakeholders.

**Program Distribution Requirements for the System Dynamics Major**

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students, completion of a minimum of 10 units of study is required in system dynamics, social science, basic science, and mathematics, and computer science as follows:

<table>
<thead>
<tr>
<th>SYSTEM DYNAMICS REQUIREMENTS</th>
<th>MINIMUM UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. System Dynamics (Note 1)</td>
<td>5/3</td>
</tr>
<tr>
<td>2. Other Social Science (Note 2)</td>
<td>5/3</td>
</tr>
<tr>
<td>3. Business (Note 3)</td>
<td>2/3</td>
</tr>
<tr>
<td>4. Mathematics/basic sciences/engineering (Note 4)</td>
<td>8/3</td>
</tr>
<tr>
<td>5. Computer Science (Note 5)</td>
<td>2/3</td>
</tr>
<tr>
<td>6. Application Area (Note 6)</td>
<td>5/3</td>
</tr>
<tr>
<td>7. MQP</td>
<td>1</td>
</tr>
</tbody>
</table>

**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.

**MINOR IN LAW AND TECHNOLOGY**

As science and technology evolve, there are growing needs for professionals who both understand science and technology and who work within the institutions of the American legal system. At all levels, from federal courts to state regulatory agencies and local planning commissions, policy makers decide issues in an environment of legal rules and principles. Yet to be effective, they must also understand how science and technology can aid their decisions, the methods and conclusions of scientific research, and the social impact of decisions. Without science, environmental regulators cannot decide on measures for hazardous waste disposal, public health officials cannot evaluate new drug therapies, utility regulators cannot authorize new sources of electric power, judges cannot construe the meaning of medical testimony, and attorneys cannot cross examine an expert witness in a product failure case. Decision makers, and those who attempt to influence them, find that they need to understand science and technology.
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. **IQP**
   
   The capstone experience must be 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.

   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.

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**MINORS IN SOCIAL SCIENCE**

A Social Science Minor is available in any of the following disciplines:

- Economics
- Sociology
- Political Science and Law
- Psychology
- System Dynamics
- Social Science

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*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
- ECON 2120 Intermediate Macroeconomics*