DEPARTMENT AND PROGRAM DESCRIPTIONS

SECTION

two

AIR FORCE AEROSPACE STUDIES

LTC EDWARD N. IRELAND, HEAD
PROFESSOR: Lt. Col. E. N. Ireland
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INTRODUCTION

The Air Force Reserve Officer Training Corps (AFROTC) program offered at WPI is designed to provide a college student the opportunity to become an Air Force commissioned officer while completing requirements for an undergraduate or graduate degree. Enrollment is voluntary and open to young men and women who are U. S. citizens of good moral character and sound physical condition who seek the challenge of being an officer in the U. S. Air Force upon graduation from college. In addition to WPI students, students at any of the **Worcester Consortium for Higher Education** institutions are also eligible to apply for Air Force ROTC at WPI.

MISSION AND EDUCATIONAL OBJECTIVES

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

Educational Objectives:

Students who successfully complete the AFROTC program will have:

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

AIR FORCE ROTC PROGRAMS

There are two traditional routes to an Air Force commission through Air Force ROTC. Entering students may enroll in the Air Force Four-Year Program. Students with at least two academic years remaining in college may apply for the Two-Year Program. However, there are opportunities for Freshmen, Sophomores, Juniors, in some cases Seniors and Graduate Students, please check with the AFROTC Detachment Staff for these special circumstances.

FOUR-YEAR PROGRAM

The more popular and preferred program is the traditional Four-Year Program. To enroll, simply register for Air Force Aerospace Studies in the fall term of the freshman year in the same manner as other college courses. There is NO MILITARY OBILGATION 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 $400 each month. POC who are not on scholarship are eligible to receive a POC tuition assistance incentive of $3000 a year.

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

TWO-YEAR PROGRAM

The Two-Year Program is available for college students with two years of undergraduate or graduate study remaining. Applicants must apply for the program no later than the beginning of Term C (spring semester) preceding those two final years. The applicant will take the Air Force Officer Qualifying Test, will be given a physical examination at no expense, and will meet a selection board.

Applicants for the Two-Year Program will attend the Air Force ROTC field training for five weeks instead of four at an Air Force base prior to their entry into the Professional Officer Course (POC). Like their four year counterparts, they are paid while at field training and will receive travel pay to and from the Air Force base hosting field training. Students accepted into the Two-Year Program will complete the Professional Officer Course as described above.

SCHOLARSHIP OPPORTUNITIES

By participating in Air Force ROTC, students may compete for Air Force scholarships ranging from two years to three years in duration. Full scholarships cover tuition, most fees, and a textbook allowance. Partial scholarships are also available which contribute up to 80% of fees and tuition, in addition to a textbook allowance. A tax-free subsistence allowance of $250 to $400 is paid to all scholarship students each academic month.

Entering freshmen may compete for an Air Force ROTC Four-Year Scholarship during their senior year in high school (deadline Dec. 1 of their high school senior year). Details of this program can be obtained by e-mailing afrotc@wpi.edu, by writing: Department of Aerospace Studies, WPI, 100 Institute Rd., Worcester MA 01609-2280, or through most high school counseling offices.

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 for GMC with one additional hour for POC.

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 Air Force customs and courtesies; squadron and flight 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 more responsible for the planning and organizing of wing activities, to include conducting the Leadership Laboratory itself.

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

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 works, service to the poor, work with local orphanages, and similar activities. Twice a year, members participate in conventions/conclaves held in various cities and attended by members from all the schools in the country sponsoring AFROTC. Membership is by nomination after completion of a one semester, project-oriented pledge program.

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

Introductory Flight Training:
The Introductory Flight Training (IFT) is a program made available to pilot candidates after the summer of their junior year. This program is designed to give flying experience to those individuals who do not possess a private pilot license. The purpose of this program is to increase the success rate of officers entering Joint Specialized undergraduate Pilot Training (JSUPT). Pilot candidates will receive ground school and 50 hours of flying time from a flight instruction program operating in accordance with Federal Aviation Regulations. At the completion of the program the student will have the opportunity to receive a private pilot license.

Base Visits:
Air Force ROTC officer candidates have the opportunity to visit Air Force bases for firsthand observation of the operating Air Force. These trips are frequently made on weekends or scheduled to coincide with school vacation periods. Officer candidates may be flown by military aircraft to an Air Force base where they spend the day, remain on base overnight, and return to campus the following day.

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 Parachute Freefall and Glider Instruction, are also available to selected volunteer officer candidates during the summer

BIOLOGY AND BIOTECHNOLOGY

J. RULFS, HEAD
PROFESSORS: D. S. Adams, J. C. Bagshaw, R. D. Cheetham, J. Miller, P. J. Weathers
ASSOCIATE PROFESSORS: T. C. Crusberg, S. M. Politz, J. Rulfs
ASSISTANT PROFESSORS: D. G. Gibson III, E. Ryder, J. A. Tyler
AFFILIATE PROFESSORS: A. Di Iorio
ADJUNCT ASSISTANT PROFESSOR/SENIOR LAB INSTRUCTOR: J. Whitefleet-Smith
ADJUNCT ASSISTANT PROFESSOR/LAB INSTRUCTOR: M. Buckholt

INTRODUCTION
Undergraduates majoring in Biology and Biotechnology have the opportunity to gain extensive knowledge of the scientific basis of biological investigation ranging from biological macromolecules, through genes and cells, to organisms and their interactions with the environment. Students also choose experiences in hands-on laboratory and field techniques in aspects of modern biology, including cell and molecular biology, bioprocess, recombinant DNA methods, microbiololgy, physiology, and environmental biology. Opportunities also exist to pursue practical exposure to methods of computational biology, including bioinformatics and simulation modeling. Students who major in biology and biotechnology will be uniquely qualified for positions in academic, industrial or governmental research facilities, or for further studies in graduate or professional (medical, dental, veterinary) schools.

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 discovery.

EDUCATIONAL OBJECTIVES

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

EDUCATIONAL OUTCOMES

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

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

BIOLOGY AND BIOTECHNOLOGY

Biology, simply stated, is the study of living organisms. Biotechnology is broadly defined as the use of organisms and their components for the manufacture or modification of products, the alteration of animals and plants, and the adaptation of microorganisms to specific tasks. Biotechnology is as old as winemaking, farming, and animal husbandry and as new as methods of DNA recombination. In the modern context, biotechnology is further defined as the use of technological research tools in deciphering questions about living organisms, and the application of engineering principles and methods to these questions.

Students may choose to pursue a generalist degree in biology and biotechnology, or to structure their academic programs within any of five concentrations: bioprocess, cell and molecular biology and genetics, computational biology, ecology and environmental biology, or organismal biology. These concentrations provide not only guidelines for course choices within the department, but also include educational opportunities that cross academic disciplines.

UNDERGRADUATE RESEARCH PROJECTS

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

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

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

BASIC CURRICULUM

Programs within the department provide a broad base of scientific information and experience with in-depth laboratory study in personally selected areas of biology and biotechnology. With your faculty advisor, you will plan your own unique program, which will include a variety of course work and research experiences.

A modern biologist also needs exposure to other sciences and mathematics in order to process experimental data, solve problems, and understand the chemical and physical rules under which biological systems operate. Students may select general chemistry, organic chemistry, biochemistry, physics, calculus or statistics to round out their scientific education.

GUIDELINES FOR SELECTION OF BB COURSES

Introductory survey courses are numbered at the 1000-level. Courses at the 2000-level introduce basic concepts in a defined area. Advanced subjects taught mostly from texts are at the 3000-level, and courses at the 4000-level are taught using mostly the original scientific literature.

Program Distribution Requirements for the Biology and Biotechnology Major

BIOLOGY and BIOTECHNOLOGY	Minimum Units
1. Mathematical Science, Physics, Computer Science, Engineering	2
2. Chemistry	5/3
3. BB 1000/2000-level	4/3
4. BB Laboratory Fundamentals (see Note 1)	1/3
5. Other Laboratory Experience (see Note 2)	2/3
6. BB 3000/4000-level (see Note 3)	5/3
7. Related Courses (see Note 4)	4/3
8. MQP	1

NOTES:
1. Chosen from among 1000- and 2000-level options, currently BB 2940 and BB 2950.
2. Chosen from among BB 3000/4000 Laboratories or from Laboratory Experience List for all Concentrations.
3. In certain cases 500-level courses are appropriate for undergraduate credit with explicit permission of the Instructor.
4. Chosen from among the Related Courses Lists for all Concentrations.

BIOLOGY and BIOTECHNOLOGY WITH CONCENTRATIONS (note 1)	Minimum Units
1. Mathematical Science, Physics, Computer Science, Engineering	2
2. Chemistry	5/3
3. BB 1000/2000-level	4/3
4. BB Laboratory Fundamentals (see Note 2)	1/3
5. Other Laboratory Experience (see Note 3)	2/3
6. BB 3000/4000-level (see Note 4)	5/3
7. Related Courses (see Note 5)	4/3
8. MQP (see Note 6)	1

NOTES:
1. Students pursuing a Concentration must fulfill all requirements for that Concentration. Specific rules and course lists for each Concentration follow. No course may count in more than one category, including university and departmental distribution requirements.
2. Chosen from among 1000- and 2000-level options, currently BB 2940 and BB 2950.
3. Chosen from among BB 3000/4000 Laboratories or from Laboratory Experience List. Appropriate courses are suggested for each Concentration.
4. Of these 5/3 Units, 2/3 must come from the appropriate approved Concentration List. In certain cases 500-level courses are appropriate for undergraduate credit with explicit permission of the instructor.
5. Chosen from among courses specified within each concentration's Related Courses List.
6. Must be approved by the MQP advisor of record as appropriate for the Concentration.

APPROVED COURSES FOR THE CONCENTRATION IN BIOPROCESS

OTHER LABORATORY EXPERIENCE

Students concentrating in Bioprocess MUST choose at least 2/3 Units of Laboratory-oriented coursework. These courses may be chosen from any combination of Biology and Biotechnology 3000- or 4000-level courses and Approved "Other Laboratory Options" below.

Suggested Courses:
BB 3513 Cell Culture Techniques for Animal Cells
BB 3516 Separation Techniques in Biotechnology
BB 3517 Fermentation
BB 3519 Protein Purification

Other Laboratory Options:
BB 3511 Nerve and Muscle Physiology
BB 3512 Molecular Genetics Lab
BB 3514 Circulatory and Respiratory Physiology
BB 3518 Molecular Biology
BB 3520 Recombinant DNA Technology
BE 562 Small Animal Surgery
CE 4060 Environmental Engineering Laboratory
CE 4061 Hydrology
CH 4150 Experimental Biochemistry
GE 2341 Geology

BB 3000/4000-LEVEL

Students concentrating in Bioprocess MUST choose 5/3 Units of course work in Biology and Biotechnology at the 3000 or 4000 level. At least 2/3 Units MUST come from the Approved Courses below.

BB 3055 Microbial Physiology
BB 4008 Cell Culture Theory and Applications
BB 4070 Separation of Biological Molecules (not available for credit in addition to BB560)
BB 505 Fermentation Biology
BB 509 Scale-up of Bioprocessing
BB 560 Separation of Biological Molecules (not available for credit in addition to BB4070)

RELATED COURSES

Students concentrating in Bioprocess must choose AT LEAST 1/3 Unit in Chemistry from the list below, but MAY NOT COUNT more than 2/3 Units in Chemistry toward this Concentration requirement. Remaining Units must be selected from "Other Courses" below:

Chemistry
CH 3510 Chemical Thermodynamics
CH 4110 Biochemistry I
CH 4120 Biochemistry II

Other Courses
CM 2011 Chemical Engineering Fundamentals
CM 2013 Applied Chemical Engineering Fundamentals
CS 1001 Introduction to Computers
CS 1005 Introduction to Programming
CS 2005 Data Structures and Programming Techniques
ES 3002 Mass Transfer

APPROVED COURSES FOR THE CONCENTRATION IN CELL AND MOLECULAR BIOLOGY AND GENETICS

OTHER LABORATORY EXPERIENCE

Students concentrating in Cell and Molecular Biology and Genetics MUST choose at least 2/3 Units of Laboratory-oriented coursework. These courses may be chosen from any combination of Biology and Biotechnology 3000- or 4000-level courses and Approved "Other Laboratory Options" below.

Suggested Courses:
BB 3512 Molecular Genetics Lab
BB 3513 Cell Culture Techniques for Animal Cells
BB 3516 Separation Techniques in Biotechnology
BB 3518 Molecular Biology Lab
BB 3519 Protein Purification
BB 3520 Recombinant DNA Technology
CH 4150 Experimental Biochemistry

Other Laboratory Options:
BB 3511 Nerve and Muscle Physiology
BB 3514 Circulatory and Respiratory Physiology
BB 3517 Fermentation
BE 562 Small Animal Surgery
CE 4060 Environmental Engineering Laboratory
CE 4061 Hydrology
GE 2341 Geology

BB 3000/4000-LEVEL

Students concentrating in Cell and Molecular Biology and Genetics must choose 5/3 Units of course work in Biology and Biotechnology at the 3000 or 4000 level. At least 2/3 Units MUST come from the Approved Courses below.

BB 3055 Microbial Physiology
BB 3080 Neurobiology
BB 3620 Developmental Biology
BB 3920 Immunology
BB 4008 Cell Culture Theory and Applications
BB 4010 Advanced Molecular Genetics
BB 4065 Virology
BB 4550 Advanced Cell Biology
BB 4910 Molecular Biology
BB 4955 Recombinant DNA

RELATED COURSES

Students concentrating in Cell and Molecular Biology and Genetics must choose at least 2/3 Units in Chemistry from the list below. Remaining Units may be selected either from Chemistry options below, or from "Other Courses" below.

Chemistry
CH 2330 Organic III
CH 4110 Biochemistry I
CH 4120 Biochemistry II
CH 4150 Experimental Biochemistry
CH 4160 Membrane Biophysics
CH 4910 Regulation of Gene Expression

Other Courses
BB 3055 Microbial Physiology
BB 3080 Neurobiology
BB 3620 Developmental Biology
BB 3920 Immunology
BB 4008 Cell Culture Theory and Applications
BB 4010 Advanced Molecular Genetics
BB 4065 Virology
BB 4550 Advanced Cell Biology
BB 4910 Molecular Biology
BB 4955 Recombinant DNA

APPROVED COURSES FOR THE CONCENTRATION IN COMPUTATIONAL BIOLOGY

OTHER LABORATORY EXPERIENCE

Students concentrating in Computational Biology MUST choose at least 2/3 Units of Laboratory-oriented coursework. These courses may be chosen from any combination of Biology and Biotechnology 3000- or 4000-level courses and Approved "Other Laboratory Options" below.

Suggested Courses:
BB 3511 Nerve and Muscle Physiology
BB 3512 Molecular Genetics Lab
BB 3514 Circulatory and Respiratory Physiology
BB 3518 Molecular Biology Lab
BB 3520 Recombinant DNA Technology
CE 4061 Hydrology

Other Laboratory Options:
BB 3513 Cell Culture Techniques for Animal Cells
BB 3516 Separation Techniques in Biotechnology
BB 3517 Fermentation
BB 3519 Protein Purification
BE 562 Small Animal Surgery
CE 4060 Environmental Engineering Laboratory
CH 4150 Experimental Biochemistry
GE 2341 Geology

BB 3000/4000-LEVEL

Students concentrating in Computational Biology must choose 5/3 Units of course work in Biology and Biotechnology at the 3000 or 4000 level. At least 2/3 Units MUST come from the Approved Courses below:

BB 3020 Computational Biology
BB 3040 Experimental Design and Data Analysis
BB 4440 Bioinformatics
BB 542 Ecological Simulation

RELATED COURSES

Students concentrating in Computational Biology must choose at least 4/3 Units from among "Approved Courses" below:

Approved Courses
BB 3020 Computational Biology
BB 3040 Experimental Design and Data Analysis
BB 4440 Bioinformatics
BB 542 Ecological Simulation
CH 4130 Biochemistry III
CS 2005 Data Structures and Programming Techniques
CS 2022/
MA 2201 Discrete Mathematics
CS 2135 Programming Language Concepts
CS 2136 Paradigms of Computation
CS 2223 Algorithms
CS 3041 Human-Computer Interaction
CS 4032 Numerical Methods for Linear and Nonlinear Systems
CS 4120 Analysis of Algorithms
MA 2051 Ordinary Differential Equations
MA 2271 Graph Theory
MA 2273 Combinatorics
MA 2431 Mathematical Modeling with ODE
MA 2621 Probability for Applications
MA 2631 Probability
MA 3231 Linear Programming
MA 3233 Discrete Optimization

APPROVED COURSES FOR THE CONCENTRATION IN ECOLOGY AND ENVIRONMENTAL BIOLOGY

OTHER LABORATORY EXPERIENCE

Students concentrating in Ecology and Environmental Biology MUST choose at least 2/3 Units of Laboratory-oriented coursework. These courses may be chosen from any combination of Biology and Biotechnology 3000- or 4000-level courses and Approved "Other Laboratory Options" below.

Suggested Courses:
BB 3511 Nerve and Muscle Physiology
BB 3514 Circulatory and Respiratory Physiology
BE 562 Small Animal Surgery
CE 4060 Environmental Engineering Laboratory
CE 4061 Hydrology
GE 2341 Geology

Other Laboratory Options:
BB 3512 Molecular Genetics Lab
BB 3513 Cell Culture Techniques for Animal Cells
BB 3516 Separation Techniques in Biotechnology
BB 3517 Fermentation
BB 3518 Molecular Biology Lab
BB 3519 Protein Purification
BB 3520 Recombinant DNA Technology
CH 4150 Experimental Biochemistry

BB 3000/4000-LEVEL

Students concentrating in Ecology and Environmental Biology must choose 5/3 Units of course work in Biology and Biotechnology at the 3000 or 4000 level. At least 2/3 Units MUST come from the Approved Courses below.

BB 3055 Microbial Physiology
BB 3110 Animal Physiology
BB 3120 Plant Physiology and Cell Culture
BB 3140 Evolution: Pattern and Process
BB 3160 Behavioral Ecology
BB 4140 Ecological Management
BB 4150 Population and Community Ecology
BB 542 Ecological Simulation

RELATED COURSES

Students concentrating in Ecology and Environmental Biology must choose 3/3 Units in Science and Engineering and 1/3 Unit in Humanities and Social Sciences from the list below.

Science and Engineering:
BB 3055 Microbial Physiology
BB 3110 Animal Physiology
BB 3120 Plant Physiology and Cell Culture
BB 3140 Evolution: Pattern and Process
BB 3160 Behavioral Ecology
BB 4140 Ecological Management
BB 4150 Population and Community Ecology
BB 542 Ecological Simulation
CE 3059 Environmental Engineering
CE 3061 Waste Water Treatment
CE 3070 Urban and Environmental Planning
CE 3074 Environmental Analysis
CE 4071 Land Use Development and Controls

Humanities and Social Sciences:
EN 3231 New England Supernaturalism
PY 2717 Philosophy and the Environment
SS 2117 Environmental Economics
SS 2311 Legal Regulation of the Environment
SS 2312 International Environmental Policy
SS 2405 The Psychological Study of Environmental Issues

APPROVED COURSES FOR THE CONCENTRATION IN ORGANISMAL BIOLOGY

OTHER LABORATORY EXPERIENCE

Students concentrating in Organismal Biology MUST choose at least 2/3 Units of Laboratory-oriented coursework. These courses may be chosen from any combination of Biology and Biotechnology 3000- or 4000-level courses and Approved "Other Laboratory Options" below.

Suggested Courses:
BB 3511 Nerve and Muscle Physiology
BB 3513 Cell Culture Techniques for Animal Cells
BB 3514 Circulatory and Respiratory Physiology
BB 3517 Fermentation
BE 562 Small Animal Surgery
CH 4150 Experimental Biochemistry

Other Laboratory Options:
BB 3512 Molecular Genetics Lab
BB 3516 Separation Techniques for Biotechnology
BB 3518 Molecular Biology
BB 3519 Protein Purification
BB 3520 Recombinant DNA Technology
CE 4060 Environmental Engineering Laboratory
CE 4061 Hydrology
GE 2341 Geology

BB 3000/4000-LEVEL

Students concentrating in Organismal Biology must choose 5/3 Units of course work in Biology and Biotechnology at the 3000 or 4000 level. At least 2/3 Units MUST come from the Approved Courses below:

BB 3080 Neurobiology
BB 3110 Animal Physiology
BB 3120 Plant Physiology and Cell Culture
BB 3140 Evolution: Pattern and Process
BB 3170 Plant Morphology and Development
BB 3620 Developmental Biology

RELATED COURSES

Students concentrating in Organismal Biology must choose at least 2/3 Units in Biology and Biotechnology from the list below. Remaining Units may be selected from additional Biology and Biotechnology below, or from "Other Courses" below:

Biology and Biotechnology:
BB 3055 Microbial Physiology
BB 3080 Neurobiology
BB 3110 Animal Physiology
BB 3120 Plant Physiology and Cell Culture
BB 3140 Evolution
BB 3160 Behavioral Ecology
BB 3170 Plant Morphology and Development
BB 3620 Developmental Biology
BB 3920 Immunology
BB 4008 Cell Culture Theory and Applications
BB 4065 Virology

Other Courses:
BE 562 Small Animal Surgery
BE 3110 Experimental Physiology
BE 4541 Biological Systems
CH 4110 Biochemistry I
CH 4120 Biochemistry II
SS 1401 Cognitive Psychology

BIOMEDICAL ENGINEERING

C. H. SOTAK, HEAD

Primary BE Faculty

PROFESSORS: R. A. Peura, C. H. Sotak
ASSOCIATE PROFESSOR: Y. Mendelson
ASSISTANT PROFESSORS: K. L. Billiar, G. D. Pins, R. D. Shonat
RESEARCH ASSISTANT PROFESSOR: K. G. Helmer

Collaborative BE Faculty

PROFESSORS: D. Cyganski, W. W. Durgin, A. H. Hoffman, F. J. Looft, R. Ludwig, J. A. Orr, P. C. Pedersen, B. J. Savilonis, , J. M. Sullivan, D. Tang
ASSOCIATE PROFESSORS: H. Ault, S. Shivkumar
ASSISTANT PROFESSORS: T. A. Camesano, E. A. Clancy, N. A. Whitmal

MISSION STATEMENT

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

EDUCATIONAL OBJECTIVES

The educational objectives of the Biomedical Engineering Department are to prepare professionals who possess fundamental knowledge of engineering and basic science and can apply these principles to solve problems in biology and medicine. Through a project-oriented curriculum, which closely embraces the WPI educational philosophy, we prepare students to engage in a lifetime of professionalism and learning.

EDUCATIONAL OUTCOMES

The Biomedical Engineering Department has established 13 educational outcomes in support of our department objectives. Accordingly, students graduating from the Biomedical Engineering Department will demonstrate:

1. An ability to apply knowledge of advanced mathematics (including differential equations and statistics), science, and engineering to solve the problems at the interface of engineering and biology (**general criterion 3a and program criteria**).
2. An ability to design and conduct experiments, as well as to analyze and interpret data from living and non-living systems (**general criterion 3b and program criteria**).
3. An ability to design a system, component, or process to meet desired needs (**general criterion 3c**).
4. An ability to function on multi-disciplinary teams (**general criterion 3d**).
5. An ability to identify, formulate, and solve engineering problems (**general criterion 3e**).
6. An understanding of professional and ethical responsibilities (**general criterion 3f**).
7. An ability to communicate effectively (**general criterion 3g**).
8. The broad education necessary to understand the impact of engineering solutions in a global and societal context (**general criterion 3h**).
9. A recognition of the need for, and an ability to engage in life-long learning (**general criterion 3i**).
10. A knowledge of contemporary issues (**general criterion 3j**).
11. An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice (**general criterion 3k**).
12. An understanding of biology and physiology (**program criteria**).
13. An ability to address the problems associated with the interaction between living and non-living materials and systems (**program criteria**).

Note: The general and specific program criteria indicated above in parenthesis meet the requirements for Biomedical Engineering accreditation by ABET (the Accreditation Board for Engineering and Technology).

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 the 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 22.

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 patients.

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 Salisbury and Higgins Laboratories as well as at the affiliated institutions previously listed.

COMBINED B.S./MASTER'S DEGREE PROGRAM

This program affords an opportunity for outstanding WPI undergraduate students to earn both a B.S. degree and a master's degree in biomedical engineering concurrently, and in less time than would typically be required to earn each degree separately. The principal advantage of this program is that it allows for certain courses to be counted towards both degree requirements, thereby reducing total class time. With careful planning and motivation, the Combined Program typically allows a student to complete requirements for both degrees with only one additional year of full-time study (five years total). However, because a student must still satisfy all graduate degree requirements, the actual time spent in the program may be longer than five years. There are two degree options for students in the Combined Program: a thesis-based master of science (B.S./M.S.) option and a non-thesis master of engineering (B.S./M.E.) option.

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 22), a biomedical engineer needs a solid background in mathematics, physical and life sciences. The distribution requirements are satisfied as follows:

BIOMEDICAL ENGINEERING	Minimum Units
1. Mathematics (See Note 1)	2
2. Basic Science (See Note 2)	2
3. Supplemental Science and Engineering (See Note 3)	2/3
4. Laboratory experience with living systems (See Note 4)	1/3
5. Biomedical Engineering and Engineering (See Note 5)	4 1/3
6. MQP (See Note 6)	1

NOTES:

1. Mathematics must include differential and integral calculus, differential equations and statistics.
2. Two courses from each of the following areas: BB, CH and PH.
3. Two courses from BB, CH or PH.
4. Experimental Physiology (BE 3110) or equivalent.
5. Thirteen courses from Biomedical Engineering (BE) or Engineering (CE, CM, EE, ES, or ME) with the following distribution: (1) seven courses from Biomedical Engineering or Engineering as specified in the WPI Catalog "Courses Qualifying for Engineering Department Areas", one of which must be an engineering design course; (2) four courses from Biomedical Engineering or Engineering at the 3000-level or above; (3) two courses in Biomedical Engineering at the 4000-level or above. A minimum of eight of the thirteen courses must be from Biomedical Engineering, not including BE 3110.
6. Must include 1/3 unit Capstone Design Experience.

Preparation for Medical, Dental, or Veterinary Schools

Students who wish to prepare for medical, dental, or veterinary school can choose any of the BME specialization areas listed above. These students should select courses that deal with basic science and the principles of engineering; however, special requirements for medical school must be met within the confines of those specialization areas. These include:

SUPPLEMENTAL SCIENCE COURSES:

Since a full year of general chemistry and physics is required, students must take one additional course in both chemistry and physics (preferably CH 1030 and PH 1140) in addition to the two in each area (CH 1010, CH 1020, PH 1110, and PH 1120) required by the BE program.

FREE ELECTIVES:

Because of the requirement of three organic chemistry courses (with labs), it is recommended that students use their two free electives for two (CH 2310 and CH 2320) of the three courses. The third course (CH 2360) would be taken outside of the BE program requirements.

Students should consult the Pre-Health Center, in addition to their BME advisor, for current information about course requirements for admission into medical or veterinary school.

BIOMEDICAL ENGINEERING PROGRAM CHART

<table>
<tr><th></th><th>FRESHMAN/SOPHOMORE</th><th>JUNIOR</th><th>SENIOR</th></tr>
<tr><td rowspan="3">COURSE RECOMMENDATIONS</td><td rowspan="2">Mathematics (6 courses)
MA 1021 (Calculus I)
MA 1022 (Calculus II)
MA 1023 (Calculus III)
MA 1024 (Calculus IV)
MA 2051 (Differential Equations)
MA 2611 (Statistics)
Biology (2 courses)
BB 2550 (Cell Biology)
BB 3102 (Physiology: Transport and Maintenance)
Chemistry (2 courses)
CH 1010 (Molecularity)
CH 1020 (Forces and Bonding)
Physics (2 courses)
PH 1110 (Physics I)
PH 1120 (Physics II)
Supplemental Science (2 courses)
Pick 2 from BB, CH, or PH
(See suggested courses from specialization areas listed below)
BioMed. Eng. (select 3 courses)
BE 1001 (Intro. to Bio. Med. Eng.)
BE 2204 (Bioelectric Foundations)
BE 2504 (Foundations in Biomechanics)
BE 2604 (Foundations in Biol. Transport)
H&A Sufficiency (2 Units)
Social Science
Physical Education</td><td>IQP
BioMed. Eng. (2 courses)
BE 3300 (BME Design)
BE 3110 (Exp. Physiol.)</td><td>MQP</td></tr>
<tr><td colspan="2">Social Science
Free Electives
Physical Education
From the biomedical engineering specialization areas listed below, select nine (9) courses from BME or other engineering disciplines (four of these courses must be at the 3000-level or above, and must include two BME courses at the 4000-level or above).</td></tr>
<tr><td colspan="3">Note: The total minimum number of BME courses, not including BE 3110, is eight (8)</td></tr>
<tr><td rowspan="10">DEGREE REQUIREMENTS</td><td>H&A Sufficiency (2 units)</td><td></td><td></td></tr>
<tr><td></td><td>IQP (1 unit)</td><td></td></tr>
<tr><td>Math/Science (4 units)</td><td></td><td></td></tr>
<tr><td>Supplemental Science (2/3 Unit)</td><td></td><td></td></tr>
<tr><td></td><td></td><td>MQP (1 unit)</td></tr>
<tr><td colspan="3">Biomedical and other Engineering Topics (13/3 Units)</td></tr>
<tr><td></td><td>BE 3110 Living Systems Lab (1/3 Unit)</td><td></td></tr>
<tr><td colspan="3">Social Science (2/3 Units)</td></tr>
<tr><td></td><td colspan="2">Free Electives (2/3 Unit)</td></tr>
<tr><td colspan="3">Physical Education (1/3 Units)</td></tr>
</table>

BIOMEDICAL ENGINEERING SPECIALIZATION AREAS

The field of Biomedical Engineering (BME) has a number of subdivisions, or specializations, that are briefly described below. Preferred course listings are given in order to help students plan their program of study in consultation with their academic advisor.

BIOMATERIALS

Students combine biology and physiology coursework with interests in materials science and engineering to understand the development, processing and performance testing of biomaterials used in medical devices. Typical MQP topics include: development of collagen-based biomaterials for orthopedic and applications and tissue engineering, evaluation of surgical adhesives, shape memory polymers in staples, fracture fixation devices and stents, investigation of the effects of sterilization on UHMWPE and growth of hydroxyapatite on collagen.

Supplemental Science (Select two courses)
Preferred choices include:
- BB 2940 – Experimental Biology
- BB 3101 – Human Physiology: Movement and Communication
- CH 2310 – Organic Chemistry I
- CH 4110 – Biochemistry I
- CH 4550 – Polymer Chemistry

Engineering (Select nine courses)
Select three fundamental engineering courses; preferred choices include:
- ES 2001 – Introduction to Materials Science
- ES 2501 – Introduction to Static Systems
- ES 2502 – Stress Analysis
- ES 2503 – Introduction to Dynamic Systems

Select two 3000-level (or higher) engineering courses; preferred choices include:
- ES 3001 – Introduction to Thermodynamics
- ME 3501 – Continuum Mechanics
- ME 3502 – Advanced Mechanics of Materials
- ME 4821 – Chemistry, Properties and Processing of Plastics

Select four 3000- and/or 4000-level BE courses; preferred choices include [Note #2]:
- BE/ME 4504 – Biomechanics
- BE/ME 4814 – Biological Materials
- BE 4828 – Biomaterials-Tissue Interactions
- BE/ME 550 – Tissue Engineering

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

BIOMECHANICS

Students apply biology and physiology coursework with continuum mechanics, biomechanics and thermofluids to understand the mechanical properties of tissues such as bones and blood vessels in both healthy and diseased states. Interactions between tissues and medical devices (e.g. orthopedic, dental) are also characterized. Typical MQP topics include: soft tissue mechanics, flow in blood vessels, joint kinematics, medical device design, sports biomechanics and rehabilitation.

Supplemental Science (Select two courses)
Preferred choices include:
- BB 2940 – Experimental Biology
- BB 3101 – Human Physiology: Movement and Communication
- CH 2310 – Organic Chemistry I
- CH 4110 – Biochemistry I
- CH 4550 – Polymer Chemistry

Engineering (Select nine courses)
Select three fundamental engineering courses; preferred choices include:
- ES 2001 – Introduction to Materials Science
- ES 2501 – Introduction to Static Systems
- ES 2502 – Stress Analysis
- ES 2503 – Introduction to Dynamic Systems

Select two 3000-level (or higher) engineering courses; preferred choices include:
- ES 3001 – Introduction to Thermodynamics
- ES 3004 – Fluid Mechanics
- ME 3310 – Dynamics of Mechanisms and Machines
- ME 3501 – Continuum Mechanics
- ME 3502 – Advanced Mechanics of Materials
- ME 3506 – Rehabilitation Engineering

Select four 3000- and/or 4000-level BE courses; preferred choices include [Note #2]:
- BE/ME 4504 – Biomechanics
- BE/ME 4606 – Biofluids
- BE/ME 4814 – Biological Materials
- BE/ME 552 – Tissue Mechanics
- BE/ME 550 – Tissue Engineering

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

BIOMEDICAL ENGINEERING SPECIALIZATION AREAS

BIOMEDICAL IMAGING

Courses are available to support the development of a student's interest in biomedical imaging, including image acquisition and processing. Students blend the disciplines of physics, chemistry, mathematics, biology, computer science, and engineering according to their individual interests. Typical MQP activities include: imaging instrumentation development, image processing and analysis, diagnosis and testing. Departmental imaging facilities and computer and software support are available.

Supplemental Science (Select two courses)
Preferred choices include:
- BB 3101 – Human Physiology: Movement and Communication
- CH 1030 – Chemistry III (Equilibrium)
- CH 4110 – Biochemistry
- PH 1130 – Introduction to 20th Century Physics
- PH 1140 – Oscillations and Waves
- PH 2501 – Photonics
- PH 2601 – Photonics Laboratory

Engineering (Select nine courses)
Select three fundamental engineering courses; preferred choices include:
- EE 2011 – Introduction to Electrical and Computer Engineering
- EE 2111 – Physical Principles of ECE Applications
- EE 2112 – Electromagnetic Fields
- EE 2311 – Continuous-Time Signal and System Analysis
- ES 2011 – Introduction to Nuclear Technology

Select two 3000-level (or higher) engineering courses; preferred choices include:
- EE 3113 – Introduction to RF Circuit Design
- EE 3204 – Microelectronic Circuits II
- ME 4922 – Theory and Practice of Laser Instrumentation

Select four 3000- and/or 4000-level BE courses; preferred choices include [Note #2]:
- BE 3011 – Bioinstrumentation and Biosensors
- BE 4011 – Biomedical Signal Analysis
- BE 4201 – Biomedical Imaging
- BE 4541 – Biological Systems
- BE 581 – Medical Imaging Systems
- BE 582 – Principles of In Vivo Nuclear Magnetic Resonance Imaging

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

BIOMEDICAL SENSORS AND INSTRUMENTATION

Students select courses to develop their ability concerning the principles, applications, and design of biomedical sensors and instrumentation systems. Students should select courses, which deal with basic science, the principles of electrical engineering, biology and physiology, signal analysis, and engineering design. Typical MQP projects include: biopotential instrumentation systems, optical sensors, noninvasive blood analyte measurements, and biological measurement systems.

Supplemental Science (Select two courses)
Preferred courses include:
- BB 2940 – Experimental Biology
- BB 3101 – Human Physiology: Movement and Communication
- PH 1130 – Introduction to 20th Century Physics
- PH 1140 – Oscillations & Waves
- PH 2501 – Photonics

Engineering (Select nine courses)
Select three fundamental ECE courses; preferred choices include:
- EE 2011 – Introduction to Electrical and Computer Engineering
- EE 2022 – Introduction to Digital Circuits & Computer Engineering
- EE 2111 – Physical Principles of ECE Application
- EE 2201 – Microelectronic Circuits I
- EE 2311 – Continuous-Time Signal & System Analysis
- EE 2312 – Discrete-Time Signal & System Analysis
- EE 2799 – Electrical & Computer Engineering Design

Select two 3000-level (or higher) engineering courses; preferred choices include:
- ES 3011 – Control Engineering
- EE 3204 – Microelectronic Circuits II
- EE 3801 – Advanced Logic Design

Select four 3000- and/or 4000-level BE courses; preferred choices include [Note #2]:
- BE 3011 – Bioinstrumentation and Biosensors (Bioinstrumentation I)
- BE 4011 – Biological Signal Analysis
- BE 4023 – Biomedical Instrumentation I
- BE 4025 – Biomedical Instrumentation II
- BE 4541 – Biological Systems

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

BIOMEDICAL ENGINEERING SPECIALIZATION AREAS

TISSUE ENGINEERING

Students combine cell biology and physiology coursework with interests in biomaterials, biomechanics or biotransport phenomena to understand the structural, mechanical and biological processes associated with designing and developing living systems to repair or replace damaged tissues or organs. Typical MQP topics include: designing and testing polymer scaffolds, measuring cellular function on scaffolds and designing bioreactors to grow constructs to repair tissues such as tendon, ligament, cartilage, skin and bone.

Supplemental Science (Select two courses)
Preferred choices include:
- BB 2940 – Experimental Biology
- BB 3101 – Human Physiology: Movement and Communication
- CH 2310 – Organic Chemistry I
- CH 4110 – Biochemistry I
- CH 4550 – Polymer Chemistry

Engineering (Select nine courses)
Select three fundamental engineering courses; preferred choices include:
- ES 2001 – Introduction to Materials Science
- ES 2501 – Introduction to Static Systems
- ES 2502 – Stress Analysis
- ES 2503 – Introduction to Dynamic Systems

Select two 3000-level (or higher) engineering courses; preferred choices include:
- ES 3002 – Mass Transfer
- ES 3003 – Heat Transfer
- ES 3004 – Fluid Mechanics
- ME 3502 – Advanced Mechanics of Materials
- ME 4821 – Chemistry, Properties and Processing of Plastics

Select four 3000- and/or 4000-level BE courses; preferred choices include [Note #2]:
- BE/ME 4606 – Biofluids
- BE/ME 4814 – Biological Materials
- BE 4828 – Biomaterials-Tissue Interactions
- BE/ME 550 – Tissue Engineering

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

PROJECT/RESEARCH AREAS

BIOMATERIALS/TISSUE ENGINEERING

Research focused on understanding the interactions between cells and precisely bioengineered scaffolds that modulate cellular functions such as adhesion, migration, proliferation, differentiation and extracellular matrix remodeling. Understanding cell-matrix interactions that regulate wound healing and tissue remodeling will be used to improve the design of tissue engineered analogs for the repair of soft and hard tissue injuries. Research areas include: 1) studies investigating the roles of microfabricated scaffolds on keratinocyte function for tissue engineering of skin 2) development of tissue scaffolds that mimic the microstructural organization and mechanical responsiveness of native tissues 3) development of microfabricated cell culture systems to understand how extracellular matrix molecules regulate epithelial cell growth and differentiation.

SOFT TISSUE BIOMECHANICS/ TISSUE ENGINEERING

Research focused on understanding the growth and development of connective tissues and on the influence of mechanical stimulation on cells in native and engineered three-dimensional constructs. Research areas include: 1) micromechanical characterization of tissues, 2) constitutive modeling, 3) creation of bioartificial tissues in vitro, and 4) the effects of mechanical stimulation on the functional properties of cells and tissues.

BIOMEDICAL SENSORS AND BIOINSTRUMENTATION

The development of integrated biomedical sensors for invasive and noninvasive blood gas and glucose monitoring. Design and in vivo evaluation of reflective pulse oximeter sensors. Microcomputer-based medical instrumentation, fiber-optic sensors for medical instrumentation, application of optics to biomedicine, physiological signal processing.

The development and testing of various invasive and noninvasive biosensors and associated bioinstrumentation. Noninvasive optical sensors for measuring glucose in diabetic individuals, urea in hemodialysis dialysate, other biochemical analytes, as well as reagentless chemistry measurements are being developed.

IN-VIVO OPTICAL IMAGING

Research directed at revealing and understanding fundamental physiologic mechanisms using optical imaging techniques in mouse models. Fluorescence, phosphorescence, absorption, and spectral imaging techniques are employed to probe cellular and physiologic events. Research areas include: 1) metabolic function and oxygenation in the brain; 2) role of oxygen in diabetic retinopathy; 3) physiologic studies in inbred, transgenic, and knockout mouse models; 4) 3-D in-vivo imaging in neural tissues; 5) spectral imaging of neural tissues during functional activation.

NUCLEAR MAGNETIC RESONANCE IMAGING AND SPECTROSCOPY
Research projects in nuclear magnetic resonance (NMR) imaging and spectroscopy stress experimental aspects of NMR and their application in both medical and non-biological areas. Major biological research projects include: (1) development of metabolite imaging and spectroscopy techniques for use in the evaluation of treatment of cancer; (2) development of NMR imaging methods to delineate the "area of risk" following stroke and assess potential therapeutic intervention; and (3) development of non-invasive methods for measuring tissue blood flow, as well as tumor oxygenation, to evaluate the response of neoplasms to radiotherapy and chemotherapy.

BACTERIAL ADHESION TO BIOMATERIALS
The mechanisms governing bacterial adhesion to teeth, contact lenses, and implanted or transdermal devices are poorly understood at this time. However, it is known that the presence of a biofilm on a biomaterial surface will lead to infection and cause an implanted device to fail. Often, removal of the device is the only option since microbes attached to a surface are highly resistant to antibiotics. Research in the laboratory is aimed at characterizing bacterial interaction forces and adhesion to biomaterials, using novel techniques to probe bacterial-surface interactions, in order to design materials that are resistant to microbial colonization.

BIOMECHANICS
Research involving the relationship between the applied stress and the response on neurons located in soft tissues as well as investigation in biotransport phenomena is being conducted at the University of Massachusetts Medical School. Flow-patterns at arterial stenosis are being investigated, and the influence of arteriosclerosis on vasculative and dynamic aortic compliance. Modeling gas transport during high frequency ventilation. Heat and mass transfer in biological systems (and thermodynamic modeling). Evaluation of osteoarthritis and osteoporosis models. Elasticity and continuum mechanics measurements of tissues and their interface with engineered biomaterials as well as biofluid and biosolid interaction.

MEDICAL IMAGING
Contrast agents for nuclear medicine. Dose reduction using new detectors. Development of new detection devices for diagnostic radiology and nuclear medicine. Characterization of image intensifiers, radiation dosimetry. Tomographic image reconstruction; scatter and attenuation correction; restoration filtering; image segmentation.

SENSORY AND PHYSIOLOGIC SIGNAL PROCESSING
Application of signal processing, mathematical modeling and other electrical and computer engineering skills to the study of issues related to human sensation and physiology. Major areas of focus are vision, hearing, tactile reception, and electromyography (EMG). In the area of vision research, digitally produced pulse code modulated patterns that evoke multicolor sensations from black and white and monochromatic flicker patterns have been produced. Hearing research is concentrating on improved signal processing in hearing aid devices to improve speech perception by the hearing impaired. The purpose of the tactile receptor studies is to develop an understanding of the stimulus encoder characteristics of tactile mechanoreceptors. In the area of EMG (the electrical activity of skeletal muscle), improvements to the detection and interpretation of EMG for such uses as the control of powered prosthetic limbs and musculoskeletal modeling are continuing.

SPECTROSCOPIC MEASUREMENT OF BLOOD AND TISSUE CHEMISTRY
Applications of optical spectroscopy for the noninvasive measurement of blood and tissue chemistry, ultimately to be able to perform chemical analysis and diagnosis without removing a sample from the patient. Currently investigating the use of near infrared spectroscopy in combination with in-vivo chemometric techniques to determine tissue pH, blood hematocrit and electrolyte concentration. Also interested in the application of this technology in the triage and treatment of trauma patients and diagnosis of vulnerable plaque.

TISSUE ENGINEERING
The Center for Tissue Engineering at UMMS focuses on the generation of tissues for clinical applications. Tissues studied include cartilage, bone, tendon, fascia, skin, spinal cord, liver, and pancreas. Of specific interest is mechanical stimulation of cells and mechanisms of mechanotransduction. Particular attention is focused on determining structure-property relationships in engineered tissues.

ULTRASOUND MEASUREMENTS
Applications under current investigation include detection of arteriosclerotic plaque and skin examination, for evaluating injuries, burns, and skin cancer. Several new research projects deal with the generation and application of coherent swept frequency signals for quantifying the medium (such as tissues) that is being examined. Doppler ultrasound is used for detection of motion, and the clinical applications include blood flow imaging and fetal heart rate monitoring. A Doppler project dealing with the detection of blood clots in the leg, a condition called deep vein thrombosis, is presently being carried out.

TEACHING LABORATORIES/FACILITIES
The following facilities are maintained by the Department of Biomedical Engineering to support teaching and project activities.

Bioinstrumentation and Biosignals Laboratory (SL 311)
This teaching laboratory provides the necessary equipment and supplies for the computer-based acquisition and processing of biological signals. It supports the laboratory component of our undergraduate-(BE 1001, BE 2204, BE 3011, and BE 4011) and graduate-level (BE 523, BE 525, and BE 551) biomedical engineering courses in bioinstrumentation, biosensors, and bioelectric signals and is also available for project activities and graduate-level research. The laboratory is equipped with digital multimeters, waveform generators, power sup-

plies, oscilloscopes, and the necessary accessories, electronic components, and data books for effective and productive hardware project development.

Biomechanical Engineering Laboratories (Higgins First Floor) *Maintained in cooperation with Mechanical Engineering* This laboratory complex provides experimental and computational facilities for the laboratory component of BME courses (BE 3101, BE/ME 4504, BE/ME 4606, and BE/ME 552), Major Qualifying Projects, and graduate research. Faculty associated with these facilities include Allen H. Hoffman, (ME, Lab Director), Brian J. Savilonis (ME), and Holly K. Ault (ME).

Included in this complex are the following individual laboratories:

Biomechanics/Biofluids Laboratory (Higgins First Floor) provides experimental facilities in the areas of biomechanics and biofluids. The laboratory has equipment for measuring force, deformation, and kinematic variables as well as fluid flow, pressure, and velocity. The laboratory contains PC-based computational and data acquisition facilities.

Rehabilitation Engineering Laboratory (Higgins First Floor) provides experimental facilities for the design, development, and testing of electro-mechanical assistive devices. The Assistive Technology Resource Center is part of this laboratory.

Computing and Imaging Facility (SL 412)
This computing facility, maintained by the College Computer Center (CCC), contains network attached PC-based personal computers for use by BME students and the general WPI community. In addition, the facility houses computer-based imaging hardware and software to support our undergraduate- (BE 4011, BE 4201) and graduate-level (BE 551) biomedical engineering courses and projects in biomedical imaging and biomedical signal processing. Multimedia support for most types of traditional and electronic presentations and demonstrations is also available in this facility through the Instructional Media Center (IMC).

MQP/Projects Laboratory (SL 415)
Because project work is a significant component of a WPI education, the department maintains a dedicated laboratory for Major Qualifying Projects (MQPs), Interactive Qualifying Projects (IQPs), and independent projects. The facility contains network-attached PC-based personal computers, computer-based data acquisition systems, general electronic testing equipment, biomechanical and biomaterial testing equipment, and other common laboratory equipment and supplies with which to complete MQPs, IQPs, and independent projects.

Physiology Teaching Facility (SL 313, SL 319)
This teaching facility supports our undergraduate- (BE 3110) and graduate-level (BE 562) biomedical engineering courses in experimental physiology and small animal surgery. The laboratory and associated animal holding quarters, contains all the necessary equipment and supplies for anesthesia, surgery, and physiologic manipulation in small animals.

CHEMICAL ENGINEERING

R. DATTA, HEAD
PROFESSORS: R. Datta, A. G. Dixon, Y. H. Ma, S. L. Matson, R. W. Thompson
ASSOCIATE PROFESSORS: W. M. Clark, D. DiBiasio, F. H. Ribeiro, B. E. Wyslouzil
ASSISTANT PROFESSORS: T. A. Camesano, N. K. Kazantzis
ADJUNCT ASSISTANT PROFESSOR: H. W. Nowick, T. Starr
AFFILIATE ASSISTANT PROFESSOR: K. M. McNamara

MISSION
The Department of Chemical Engineering at WPI is dedicated to providing excellent education to undergraduate and graduate students in chemical engineering, and to vigorously pursuing discovery, creation, and dissemination of knowledge at the frontiers of chemical engineering. Chemical engineers are uniquely positioned to continue to contribute to the betterment of society through advancements in new materials, biomedicine, alternative energy, transportation, environmental pollution abatement, resource conservation, and sustainable development. The Department aspires to contribute to this vision by achieving national distinction in selected areas of scholarly inquiry and by educating men and women to become leaders in industrial practice, civil service, education, and research. The Department strives to produce technically competent and socially aware chemical engineers through project-based, innovative, and rigorous educational programs that promote global and societal awareness, innovative thinking, and life-long learning skills.

OBJECTIVES
The Chemical Engineering Department has established the following objectives of the undergraduate program in support of our mission and that of the Institute.

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

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

Objective 1

1.1 Chemical engineering graduates will possess a working knowledge of the fundamentals of chemistry, physics, and mathematics, including knowledge of advanced elective science subjects such as organic and inorganic chemistry, material science, and biochemistry, etc.

1.2 Chemical engineering graduates will possess a working knowledge of conservation principles and their applications, physical and chemical equilibria, transport and rate processes, separation processes, chemical process control, and reaction engineering.

Objective 2

2.1 Chemical engineering graduates will be able to formulate, analyze, and solve practical chemical engineering problems.

2.2 Chemical engineering graduates will be able to design experiments, safely gather and analyze data, and apply the results to address practical chemical engineering problems.

2.3 Chemical engineering graduates will be able to use appropriate mathematical concepts and methods to solve chemical engineering problems.

2.4 Chemical engineering graduates will be able to design a chemical system, process, or component with consideration of realistic constraints including practical, economic, environmental, safety, ethical, social, and political implications.

2.5 Chemical engineering graduates will be able to use computers effectively for solving chemical engineering problems.

Objective 3

3.1 Chemical engineering graduates will be able to function and work effectively alone and in a team environment, including multidisciplinary teams.

3.2 Chemical engineering graduates will posses an appreciation of professional, ethical, and contemporary issues, and the societal and global impact of chemical engineering processes.

3.3 Chemical engineering graduates will possess self-learning skills to ensure life-long learning.

3.4 Chemical engineering graduates will possess an appreciation for the humanities and social sciences.

3.5 Chemical engineering graduates will be able to use their chemical engineering education to serve the chemical engineering profession or a related profession or pursue advanced studies.

3.6 Chemical engineering graduates will have selected technical elective courses, concentrations, projects, and minors that satisfy their professional interest or career goals.

Objective 4

4.1 Chemical engineering graduates will be able to write coherent, concise, and accurate technical reports.

4.2 Chemical engineering graduates will be able to make concise and effective oral presentations.

INTRODUCTION

Chemical engineers solve a wide variety of problems utilizing chemistry and engineering principles. Chemical engineers are vital to a broad range of material technologies such as plastic parts for automobiles, ceramic engine components, high-performance food packaging materials, nanofabrication technology, optoelectronic devices and modern construction materials. The fields of energy and transportation rely heavily on chemical engineering. Chemical engineers have been key contributors in the development of designer gasoline to meet new product performance and emission requirements; liquid fuels from natural gas, coal, shale; batteries with high energy density; and novel energy-conversion technology such as fuel cells and solar cells. Many technologies to improve public health depend significantly on chemical engineering such as biomaterials, biomedical devices, medical diagnostics, the chemical synthesis of drugs, computer-aided drug design, the genetic engineering of therapeutic proteins, drug delivery systems and medical imaging technology. Finally, chemical engineering plays a dominant role in most environmental technologies. Examples are: atmospheric chemistry, product life cycle analysis, bioremediation, environmental risk and impact analysis, environmental friendly manufacturing technology and products, separation and conversion technologies for waste reduction and the cleanup of contaminated sites. Although the department strives to give all students a broad education, students can learn more in a given area of concentration by directing their course and project work to emphasize those areas.

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 22), students wishing to receive the ABET-accredited degree designated "Chemical Engineering" must satisfy certain distribution requirements. These requirements apply to 10 units of study in the areas of mathematics, basic science, engineering science and design, and 2 units of advanced chemistry as follows:

Requirements	Minimum Units
1. Mathematics and Basic Science (Notes 1, 2).	4
2. Engineering Science and Design (Notes 3, 4).	6
3. Advanced Chemistry (Note 5).	2

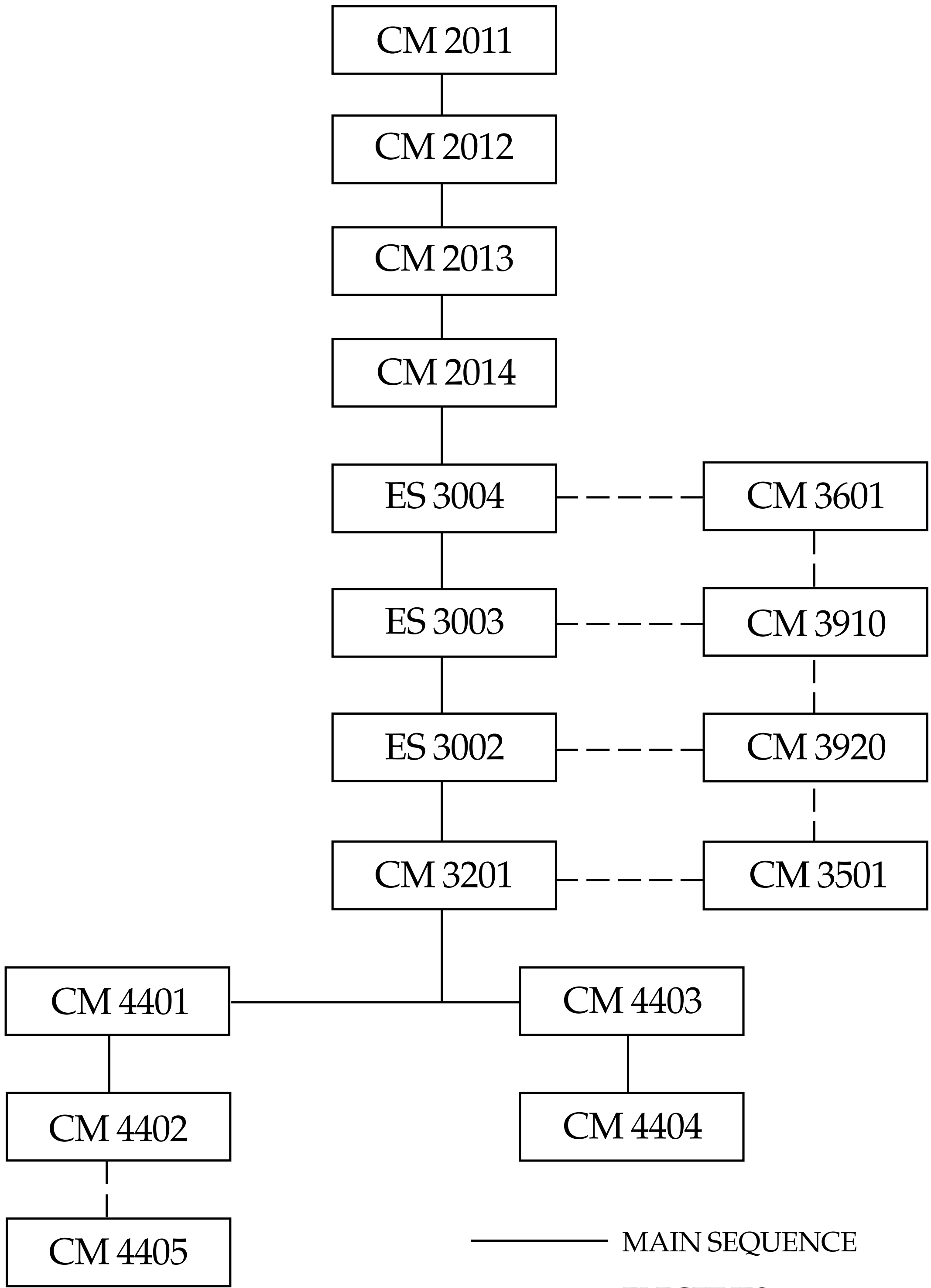
NOTES:

1. Must include differential and integral calculus and differential equations.
2. Must include 2 courses in physics.
3. Must include 1 unit of MQP, 1/3 unit of capstone design experience (e.g. CM 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.
4. Must include at least 4 units from the following list of core chemical engineering courses: CM 2011, CM 2012, CM 2013, CM 2014, ES 3004, ES 3003, ES 3002, CM 3201, CM 3501, CM 4401, CM 4402, CM 4403, CM 4404, CM 4405.
5. All CH courses qualify except CH 1010, CH 1020, and CH 1030 which are basic science. Up to 1 unit of Advanced Chemistry may be double counted as both Advanced Chemistry and Basic Science. One course of Advanced Natural Science (2000 level and above BB, PH, GE) may be substituted for one Advanced Chemistry course.

CAPSTONE DESIGN REQUIREMENT

Students may elect to satisfy WPI's capstone design requirement in Chemical Engineering by either of two routes. The preferred manner for the student to satisfy this degree requirement is to successfully complete the design course, CM 4404, which by its nature is the very essence of capstone design as described by the chemical

CHEMICAL ENGINEERING SUGGESTED COURSE SEQUENCE



engineering professional society, AIChE. Alternatively, at least 1/3 unit of the MQP may be designated as "capstone design." This option must be chosen at the time the student and the advisor agree to the content and scope of the project, and so noted on the student's project registration form.

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.

REQUIREMENTS

Concentrations within the Chemical Engineering 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. The two units of study will include at least one unit of coursework from a designated list of courses for the Concentration (a). The remaining one unit of work within the concentration area can be selected from additional courses from the designated list (b), or from the IQP, portions of the Sufficiency, or the Social Science requirement, when the course or project work supports a coherent and focused program of study in the subject area of the Concentration.

A coherent and focused program of study must be preapproved by the Department Program Review Committee. It is the student's responsibility to develop an integrated program that satisfies WPI's requirements and his/her own career aspirations. Therefore, students should plan their Concentration work with careful consultation of their Academic Advisor and the Program Review Committee. The Program Review Committee should be notified of plans for completing a Concentration before the student begins work on the Concentration. If IQP or Sufficiency work is to be used it must be certified as pertaining to the Concentration subject area by the IQP or Sufficiency advisor. The written certification should also state how many units (1/3, 2/3, or 1) the project advisor recommends be counted towards the Concentration.

(a) Experimental CM courses that emphasize the Concentration subject matter may also be used to fulfill this requirement.
(b) In special cases other courses may be approved by petition to the Program Review Committee.

DESIGNATED LISTS OF COURSES

For each Concentration a minimum of one unit of coursework must be selected from the lists of courses given below. Courses in these lists can also be counted as Basic Science, Advanced Chemistry, or Engineering Science and Design to fulfill distribution requirements as indicated. Students are also reminded that one course of Advanced Natural Science (2000 level and above PH, BB, or GE) may be substituted for one Advanced Chemistry course in meeting the department's distribution requirements. Some courses not on this list may be approved for a Concentration by petition to the Program Review Committee.

CHEMICAL ENGINEERING WITH BIOCHEMICAL CONCENTRATION

Basic Science:
Any BB course. No more than one 1000 level course may be counted, however. Recommended courses include:

BB 2002 Microbiology
BB 3055 Microbial Physiology
BB 4008 Cell Culture Theory and Applications
BB 4070 Separation of Biological Molecules
BB 505 Fermentation Biology
BB 507 Cell Culture
BB 560 Separation of Biological Molecules

Engineering Science and Design:
BB 509 Scale-Up of Bioprocessing
CM 521 Biochemical Engineering
BE 1001 Introduction to Biomedical Engineering

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

CHEMICAL ENGINEERING WITH BIOMEDICAL CONCENTRATION

Basic Science:
(at most, one of these three)
- BB 1030 Introduction to Biological Macro Molecules
- BB 2550 Cell Biology
- BB 2940 Experimental Biology I

BB 3110 Animal Physiology
BB 4065 Virology

Engineering Science and Design:
BE 1001 Introduction to Biomedical Engineering
BE/ME 4504 Biomechanics
BE/ME 4606 Biofluids
BE/ME 4814 Biomedical Materials

CHEMICAL ENGINEERING WITH ENVIRONMENTAL CONCENTRATION

Basic Science:
GE 2341 Geology
BB 2040 Principles of Ecology

Engineering Science and Design:
CM 3910 Chemical and Environmental Technology
CM 3920 Air Quality Management

(at most, one of these three)
- CE 3059 Introduction to Environmental Engineering
- CE 3070 Introduction to Urban and Environmental Planning
- CE 3074 Environmental Analysis

CE 3060 Water Treatment
CE 3061 Wastewater Treatment
CE 4060 Environmental Engineering Lab.
CE 4061 Hydrology

CHEMICAL ENGINEERING WITH MATERIALS CONCENTRATION

Engineering science and design:
CM 3601 Chemical Materials Engineering
ES 2001 Introduction to Material Science
CM 543 Molecular Sieves
CM 508 Catalysis and Surface Science of Materials
ME 2820 Materials Processing
ME 3811 Microstructure Analysis and Control
ME 4813 Ceramics
ME 4814 Biomedical Materials
ME 4821 Chemistry, Properties, and Processing of Plastics
ME 4840 Physical Metallurgy
ME 4850 Solid State Thermodynamics

Advanced chemistry:
CH 4550 Polymer Chemistry

MAJOR SUB-AREAS WITHIN DEPARTMENT

The areas of specialization normally available are closely tied to the research programs pursued by the faculty. Undergraduates can become involved in these areas to the extent they desire by properly selecting MQPs and by pursuing advanced courses or IS/Ps. The areas of specialization are as follows:

Biochemical Engineering
Bioremediation
Chemical Kinetics, Catalysis, and Reaction Engineering
Environmental Engineering
Fuel Cells
Material Science and Engineering
Membrane Technology
Process Control
Zeolite Technology

RECOMMENDED PROGRAM

Students who select chemical engineering or related fields will progress through the chemical engineering sequence as shown in the chart on page 81: first, by becoming familiar with the chemical engineering fundamentals; second, by studying the engineering sciences; and third, by becoming involved in chemical engineering design. In addition, specialized science and technology studies are recommended. This progress can be achieved by judicious selection of courses, projects, and IS/Ps.

In all program planning, students should work closely with their academic advisors not only to fulfill their personal interests, but to provide a sound professional background for a successful career in chemical engineering.

RELATED COURSES

Courses are offered either by the department faculty (CM) or by the engineering faculty under the Engineering Science (ES) label to provide the necessary background in each of the areas indicated.

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.

Areas of specialization in the department currently are:

Adsorption	Nucleation Phenomena
Aerosol Science	Mass Transfer
Biochemical Engineering	Materials Processing in Space
Bioremediation	Process Control
Catalysis	Reaction Engineering
Diffusion	Scientific Computing
Fuel Cells	Separation Processes
Inorganic Membranes	Thermodynamics
Kinetics	Zeolites

CHEMISTRY AND BIOCHEMISTRY

J. P. DITTAMI, HEAD
PROFESSORS: H. Beall, R.E. Connors, J.P. Dittami, N.K. Kildahl, W.G. McGimpsey, J.W. Pavlik, A.A. Scala, C. Sotak, S.J. Weininger
ASSOCIATE PROFESSORS: J.M. Arguello, W.D. Hobey, K.N. Wobbe
ASSISTANT PROFESSORS: C.D. Fairchild, J.C. MacDonald, V. Thalladi
RESEARCH PROFESSOR OF CHEMISTRY: L.H. Berka

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.

EDUCATIONAL 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
- achieve high ethical standards
- learn independently

OVERVIEW

Students in the Department of Chemistry and Biochemistry (CBC) may major in either *chemistry* or *biochemistry*. Chemistry is concerned with the structure and transformations of matter, the design and synthesis of new substances, and the potential applications of these substances. Biochemistry is concerned with understanding the chemistry of life at the molecular level. Both disciplines create new knowledge that benefits humanity in countless ways. CBC is deeply committed to the advancement of knowledge through the research programs of its faculty. The department is also strongly committed to the communication of this knowledge to its major students and to students in other majors requiring a strong foundation in chemistry. Via its program of major qualifying projects, CBC enables its undergraduate majors to take part in this exciting activity of developing new scientific knowledge at the same time that they are learning the ideas and concepts that allow rationalization of this knowledge at the atomic/molecular level of matter.

It is an exciting time to be a chemist or biochemist. Chemists are becoming adept at creating and manipulating new molecules to achieve desired ends. The blossoming area of nanoscale technology depends directly on the ability of the chemist to create molecules that function in a specific mechanical or electrical way. Molecules can be designed to have one shape under some circumstances and a different shape in others. This suggests the "on" or "off" type application needed in computer memory design. Molecules called carbon nanotubes have been designed that function as molecular wires. Even DNA, the molecule of heredity, has been shown by a chemist to function as a molecular wire. Chemists are now able to design and synthesize in the laboratory molecules that serve as medicines and/or drugs. Further, they can carry out "design changes" on existing medicines or drugs that result in even more effective agents. Chemists can use lasers and coupled spectroscopic methods to "photograph" movements of atoms in individual molecules that occur in less than 1 femtosecond (10^{-15} s). Thus the possibilities for exciting research in today's chemistry laboratory are almost limitless.

At the same time, biochemists have made tremendous advances in understanding the molecular basis for life since the elucidation of the molecular structure of DNA in 1953. Using modern biochemical tools such as restriction enzymes, PCR (polymerase chain reaction) and cloning, biochemists are well on the way to determining the entire human genome (that is, identifying all of the genes present in human chromosomes, and the proteins that these genes encode). Detailed structures of the active sites of enzymes have enabled biochemists to understand the mechanisms by which these fascinating molecules catalyze specific chemical reactions. These studies have in turn made it possible to use enzymes as catalysts for industrial processes. Progress in biochemistry in the last half of the 20th century was remarkable; it will only get better in the 21st.

BIOCHEMISTRY

Biochemistry is a major for students who wish to work at the interfaces of biology, chemistry and medicine. Biochemists seek to understand at the molecular level the complex chemical structures and accompanying reactions that determine biological processes such as metabolism, reproduction and growth, and their regulation through chemical messenger-receptor interactions in the immune, endocrine and nervous systems. The distribution requirements represent a balance between chemistry and biology, and between lecture and laboratory, while the overall program develops the distinct professional perspective needed to bridge molecular science to physiology.

Students who graduate with a degree in Biochemistry are well qualified for positions as professional biochemists in the pharmaceutical industry and large hospitals in areas such as drug-receptor research, bioanalytical chemistry and drug metabolism, and in the biotechnology field in jobs dealing with protein isolation, purification and modification for medical use, as well as in a variety of other employment opportunities. The program also provides excellent preparation for those who intend to further their studies in Biochemistry or related fields (e.g. Pharmacology or Immunology) at the graduate level.

Since Biochemistry embodies in its distribution requirements all the technical courses needed for admission to medical, dental and veterinary schools, it is the major of choice for prehealth professionals.

Major Qualifying Projects may be carried out under the direction of a member of the Department of Chemistry and Biochemistry or any one of the Associated Faculty listed below; see their respective department descriptions for further details. MQP opportunities are also available at research centers such as the University of Massachusetts Medical Center, Tufts University School of Veterinary Medicine, and St. Vincent Hospital.

Program Distribution Requirements for the Biochemistry Major

In addition to the WPI requirements applicable to all students (see page 22), students wishing to graduate with a degree in biochemistry must meet the *distribution requirements* detailed below.

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

Notes:

1. The mathematics in MA 1021-MA 1024 or the equivalent is recommended. The physics in PH 1110-PH 1120 or equivalent is recommended.
2. These four units must include one unit of organic, one unit of biochemistry, and 1/3 unit each of physical (3000 level or higher) and inorganic chemistry (3000 level or higher).
3. These 1 2/3 units must include 1/3 unit of cell biology, 1/3 unit of genetics, and 2/3 unit of advanced work (3000 level or higher).
4. This unit must include a minimum of 1/3 unit in Chemistry and Biochemistry, and a minimum of 1/3 unit in Biology.
5. Any course in the natural sciences (not used to satisfy another requirement) or in computer science may be used to satisfy this requirement.

AMERICAN CHEMICAL SOCIETY APPROVAL AND CERTIFICATION

CBC and its biochemistry program are approved by the American Chemical Society (ACS). Graduates who complete a program satisfying the ACS recommendations are *certified to the society* by the department. Certification signifies that these graduates have completed a program meeting the ACS standards.

The Distribution requirements provided above are considered by CBC to constitute the minimum coursework necessary to achieve a degree in biochemistry. Additional courses are necessary to be eligible for ACS certification. The following section provides detailed recommendations for both non-certified and certified degrees in biochemistry.

RECOMMENDATIONS FOR STUDENTS

A typical Biochemistry curriculum for a non-ACS certified degree 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 1001 (Term B) 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.

Year	Term A	Term B	Term C	Term D
First	CH 1010 HU MA	CH 1020 BB 2550 MA	CH 1030 BB 2920 MA	CH 1040 HU MA
Second	CH 3510 CH 2640 HU	CH 2310 PH SS	CH 2320 CH 2660 HU	CH 2330 CH 2670 HU
Third	CH 4110 BB Lab PH	CH 4120 PH IQP	CH 4130 CH 3410 IQP	CH 4150 SS IQP
Fourth	MQP Elective Elective	MQP Elective Elective	MQP CH 4160 Elective	MQP CH 4190 Elective

A typical curriculum for an ACS-certified degree in biochemistry is given below.

Year	Term A	Term B	Term C	Term D
First	CH 1010 HU MA	CH 1020 BB 2550 MA	CH 1030 BB 2920 MA	CH 1040 HU MA
Second	CH 3510 PH HU	CH 2310 PH HU	CH 2320 CH 2660 HU	CH 2330 SS HU
Third	CH 4110 BB Lab SS	CH 4120 Elective IQP	CH 4130 CH 3410 IQP	CH 4150 Elective IQP
Fourth	Elective MQP Elective	Elective MQP Elective	CH 4160 MQP Elective	CH 4190 MQP Elective

Students seeking the ACS certified degree should study calculus through multivariate analysis, linear algebra, and physics (mechanics and electricity/magnetism).

ASSOCIATED BIOCHEMISTRY FACULTY

D. S. Adams (BB), J. C. Bagshaw (BB), T. C. Crusberg (BB), G. D. J. Phillies (PH), S. M. Politz (BB), J. Rulfs (BB), E. Ryder (BB), P. J. Weathers (BB).

CHEMISTRY

Chemistry is a fundamental science concerned with discovering new knowledge about the structure, properties, and reactivities of existing forms of matter; and with the creation of new forms of matter by manipulating atoms and molecules in the laboratory. The ability of chemists to actually make new substances distinguishes chemistry from any other science, in which the practitioners are limited to studying what is already there. The knowledge created by fundamental scientific study allows us to understand our world better and to make it a more hospitable place in which to live.

In addition to its intrinsic value, chemistry is central to other areas of human endeavor, including materials science and engineering, biology, medicine, electronics, law enforcement, and even psychology. Chemistry is inherently experimental, but experiments are performed within a theoretical framework that enables interpretation of experimental results and points the way to new, fruitful areas for investigation.

Many careers are available to a chemistry graduate. Some elect to pursue an advanced degree in graduate school, medical school, veterinary school, or law school. Others decide to seek employment in industry, government, or health care. Still others may choose to pursue a teaching career. Chemistry provides an exceptionally good background for a wide variety of careers not traditionally associated with chemistry, but in which the expertise and thinking patterns of the chemist may be applicable. Examples include oceanography, environmental control, materials science, biology, biomedical engineering, mental health, and patent law. A high percentage of WPI chemistry graduates seek advanced degrees at prestigious graduate schools nationwide, while others pursue careers in many of the areas mentioned above.

Program Distribution Requirements for the Chemistry Major

In addition to the WPI requirements applicable to all students (see page 22), 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 (Note 2).	4
3. Additional Science/Engineering (Note 3).	3 2/3

Notes:

1. Must include differential and integral calculus and at least 2/3 units of physics.
2. Must be above the level of general chemistry (2000 level or higher). These 4 units must include courses in experimental chemistry (either 4/3 unit or 3/3 unit), inorganic chemistry (1/3 unit), organic chemistry (3/3 unit), physical chemistry (3/3 unit), and biochemistry (either 1/3 unit or 2/3 unit, depending on the number of experimental chemistry courses

taken). At least 2/3 units must be at or higher than the 4000 level.

3. Distributed among the MQP, the natural and physical sciences, computer science, mathematics, and engineering (and including general chemistry, CH 1010-1040).

PREVIOUS DISTRIBUTION REQUIREMENTS FOR CHEMISTRY

The above distribution requirements apply to all students whose matriculation date is after May 1, 2003. Students who matriculated prior to May 1, 2003, should consult the catalog for their year of entry or the Chair of the Chemistry Distribution Review Committee.

AMERICAN CHEMICAL SOCIETY APPROVAL AND CERTIFICATION

CBC and its chemistry program are approved by the American Chemical Society (ACS). Graduates who complete a program satisfying the ACS recommendations are *certified to the society* by the department. Certification signifies that these graduates have completed a program meeting the ACS standards.

The Distribution requirements provided above are considered by CBC to constitute the minimum coursework necessary to achieve a degree in chemistry. Additional courses are necessary to be eligible for ACS certification. The following section provides detailed recommendations for both non-certified and certified degrees in chemistry.

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.

The subject matter of chemistry was traditionally divided into the areas of inorganic, organic, physical, and analytical chemistry to aid in the organization and presentation of the subject. Although burgeoning knowledge in and applications of chemistry have made this system of compartmentalization largely obsolete in the research sphere, courses in chemistry are still organized by this older system. Every chemist should have a sound background in each of these traditional areas precisely because new directions in chemistry require an ever-broader grasp of physical and chemical principles. In addition, because chemistry is an experimental (i.e., laboratory-driven) science, familiarity with laboratory operations is essential for understanding the subject matter and for developing the practical skills needed for project work and for the pursuit of further education or a career. Four laboratory courses are designed to fulfill this need. It is strongly recommended that they be taken in the second year to provide the basis for project work in the remaining years. Finally, basic knowledge of biochemistry is considered essential.

The following sequence of courses, recommended to provide fundamental background in chemistry, will result in a non-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 a Non-ACS-Certified Degree in Chemistry

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

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

Recommended CBC Courses for an ACS-Certified Degree in Chemistry

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

*Because this course is offered every other year, some students may have to take it in Term D of the third year.

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

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 helath related professions, such as the pharmaceutical industry, upon graduation. Possible employment positions are numerous and expected to increase in the future.

Course Requirements

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

- Three biomedically oriented courses selected from the following list must be included in the distribution requirements:
  - CH 4110 Biochemistry I
  - CH 4120 Biochemistry II
  - CH 4130 Biochemistry III
  - BB 4910 Advanced Molecular Biology
  - BB 4955 Recombinant DNA Principles and Applications
  - CH 539 Molecular Pharmacology
- 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 533 Physical Organic Chemistry
  - CH 538 Medicinal Chemistry
  - CH 554 Molecular Modeling
- In addition to the above course requirements, chemistry majors must complete an MQP in the medicinal chemistry area, approved by the Program Coordinator. Examples of available projects are:
  - Synthesis of huperzine analogs. New acetylcholinesterase inhibitors for treatment of Alzheimer's.
  - Synthesis of opiate analogs.
  - Synthesis and testing of compounds that influence transport properties of biological membranes.

PROJECT ACTIVITY

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

Some students, particularly those in biochemistry, choose to do their MQPs at off-campus laboratories. Biochemistry projects have recently been completed at the University of Massachusetts Medical Center and at St. Vincent's Hospital.

Faculty in the department of chemistry and biochemistry participate in a range of IQP activities involving students from all disciplines. Some recent examples of IQPs supervised by chemistry and biochemistry faculty include

- Soviet science fiction
- Teaching science in the public schools
- Physical environment, human thought, and creativity
- Heavy metal pollution in the Nashua River
- Health effects of radon in Worcester
- Nanotechnology and society

IQP activities are administered through the Projects & Registrar's Office.

INFORMATION FOR NONMAJORS

Chemistry is often called the "central science" because it underlies so much of human activity. Some fundamental understanding of the central science is essential for anyone planning a career in science or technology. The four-course sequence CH 1010-1040 is recommended to provide this fundamental background.

Students interested in physics, chemical engineering, biology, biotechnology, biomedical engineering, medicine, or veterinary science should take more advanced courses in chemistry. The sequence of organic chemistry courses, CH 2310-2330 and CH 2360 (laboratory) provides essential background for biology, biotechnology, plastics, and polymer science. Students planning to attend medical school must take CH 2310, CH 2320, and CH 2360 to satisfy medical school entrance requirements.

Other advanced chemistry and biochemistry courses may be appropriate for particular areas of interest. Students should seek advice from their academic advisors and the chemistry/biochemistry faculty.

AREAS OF SPECIALIZATION IN CHEMISTRY AND BIOCHEMISTRY

Computational Chemistry and Molecular Modeling
Forensic Studies
Gene Regulation
Ion Transport
Materials
Medicinal Chemistry
Membrane Proteins
Molecular Spectroscopy
Nanoscale Design
Natural Products Synthesis
Plant-Virus Biochemistry
Photochemistry
Photophysics
Sensors
Supramolecular Chemistry

CIVIL AND ENVIRONMENTAL ENGINEERING

F. L. HART, HEAD
PROFESSORS: J. F. Carney, T. El-Korchi, R. W. Fitzgerald, F. L. Hart, J. C. O'Shaughnessy
ASSOCIATE PROFESSORS: L. D. Albano, R. A. D'Andrea, M. S. FitzPatrick, P. Jayachandran, P. P. Mathisen, R. Pietroforte, M. Ray, G. F. Salazar
ASSISTANT PROFESSOR: J. Bergendahl, R. Mallick, J. Plummer

MISSION STATEMENT

The Civil and Environmental 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 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.

EDUCATIONAL OBJECTIVES

1. A graduate should be able to apply the fundamental principles of mathematics, science, and civil engineering to analyze and design a component, process or system.
2. A graduate should have the interpersonal and communication skills, an understanding of ethical responsibility, and a professional attitude necessary for a successful engineering career.
3. A graduate should have the ability to engage in life-long learning.
4. A graduate should have an appreciation for the interrelationships among basic knowledge, technology, and society.

CEE 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 specialty 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.

INTRODUCTION

The major designated as "Civil Engineering" is the only program accredited by the Accreditation Board for Engineering and Technology (ABET) within the Department of Civil Engineering.

The broad range of work in civil and environmental engineering practice allows an individual to contribute professionally in a variety of different ways. On the one hand, the engineer may be involved in the broad scope of planning and managing the successful completion of a complex project that benefits our society. Examples of these types of projects include water resources and facilities; wastewater treatment facilities; hazardous or solid waste disposal systems; site design; buildings of all types; or transportation systems, such as highways and bridges, tunnels, mass transportation, airports, or harbor facilities. On the other hand, the engineer may wish to specialize and become expert in the professional activities associated with one of the many subdisciplines, such as structural engineering, environmental engineering, transportation engineering, geotechnical engineering, or materials engineering.

You have enormous flexibility in defining your educational program at WPI, and academic planning is one of the more important activities in which you will engage. With some limitations, you may specialize in one area, or you may develop a broad educational program that involves several subdisciplines. For most students, it is important to develop a program that has a broad overall structure, and, at the same time, has the flexibility to be modified with little disruption as conditions and your growth in understanding evolve. You should work closely with your advisors to develop a program that meets WPI and ABET professional requirements, while at the same time meeting your objectives and providing opportunities for explorations and educational expansion.

In developing your educational program, it is possible, and often desirable, to construct a general civil engineering program with focus on two or more of the subdisciplines. This type of program allows maximum flexibility and employment opportunities upon graduation. It also is possible to develop a program that provides a concentration of studies in one subdiscipline with minimal breadth in related subdisciplines. Each of these types of goals has advantages and limitations from both professional and educational viewpoints. The Civil and Environmental Engineering Department advisors can provide you with a document that provides guidance and sample programs within the context of WPI and ABET requirements.

The professional career opportunities for civil engineers are many and broadly varying. Normally, it is valuable to become a registered professional engineer as early in a career as possible. The usual route to becoming a registered professional engineer involves (a) obtaining a degree from an ABET-accredited program; (b) passing the Fundamentals of Engineering Examination (FEE); (c) acquiring the necessary amount of professional level engineering experience; and (d) passing the professional engineers examination of the appropriate state licensing board. One can get the ABET accredited program in civil engineering at WPI. It is recommended that you take the Fundamentals of Engineering Examination (FEE) during the last year at WPI. This educational background should prepare you for the entry level engineering work necessary to complete the other professional registration requirements.

It is possible to enter the professional work force after receiving the BS degree. An additional opportunity that should be considered sometime before the final year is the integration of the BS with a MS degree. These degrees can be earned with five complete academic years of education. It is becoming more common to consider the MS degree as the first professional degree. Individuals who have recognized career objectives should consider this opportunity. The integration allows both graduate and undergraduate courses to be incorporated into the programs with possible reductions in costs and time. It is also possible, of course, to obtain advanced degrees in civil engineering specialty disciplines or in other fields concurrently with professional employment through a continuing education program.

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 22), students wishing to receive the ABET-accredited degree designated *"Civil Engineering"* must satisfy certain distribution units of study in the areas of mathematics, basic science, and engineering science and design as follows:

Requirements	Minimum Units
1. Mathematics and Basic Science (Notes 1,2).	4
2. Engineering Science and Design (including the MQP) (Note 3,4,5,6).*	6

Notes:

1. Mathematics must include differential and integral calculus and differential equations.
2. Must include both chemistry and physics with a minimum of two courses in either.
3. A minimum of 4 units of work must be within the Civil Engineering area. All CE courses including the MQP, ES 2503, 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, 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 3054, CE 4046, and CE 4060. Alternately, an appropriate laboratory experience could also be accomplished by a student through careful planning of course, project and laboratory work and approval by petition through the Department Program Review Committee.
6. Must include 1/3 unit of Capstone Design Experience.

RECOMMENDED FUNDAMENTAL BACKGROUND

MATHEMATICS AND BASIC SCIENCE

It is essential that civil engineering students be well grounded in mathematics, the basic language of all engineers. For students with a normal secondary school background, the following courses should be taken: MA 1021, MA 1022, MA 1023, and MA 2051. At least one, and preferably several additional courses are valuable to a civil engineering education and may be selected from the following courses, depending upon the student's interests: MA 1024, MA 2210, MA 2071, or MA 2611. MA 2210, Mathematical Methods in Decision Making, in particular, is useful in working with civil engineering systems. As students progress and begin to develop a keen interest in a specific area of civil engineering, they should be prepared to seek additional mathematical support for advanced-level work. Advanced placement from high school, properly included in the WPI transcript, will be given appropriate credit.

A background in basic sciences is required. The student must include both physics and chemistry with a minimum of two courses in either. Possible basic science courses are PH 1110, PH 1120, PH 1130, CH 1010, CH 1020, CH 1030, CH 1040, GE 2341, BB 1001 and BB 2002. Advanced placement from high school, properly included in the WPI transcript, will be given appropriate credit.

ENGINEERING SCIENCE AND DESIGN

Engineering sciences have their roots in mathematics and basic sciences, but carry knowledge further toward creative application. Courses in engineering science provide a bridge between basic science and engineering practice. A student should select the engineering sciences that are appropriate for advanced professional design courses, and then fill out any additional requirements of engineering science with electives that provide a broad base for engineering practice. Consideration should be given to those engineering sciences required for the Fundamentals of Engineering Examination (FEE). At least one course must be from outside of the major area. Please note that ES 2503 and ES 3004 are regarded as civil engineering courses, and are an important part of the FEE examination. The engineering science requirement can be met by selecting a combination of courses from several disciplines. A partial listing of applicable courses from other disciplines that are useful for civil and environmental engineering students includes ES 3001, EE 3601, and FP 3070. Civil engineering courses that are considered engineering science include: CE 2000, CE 2001, CE 2002, CE 2020, CE 3024, CE 3026, CE 3041, and CE 4007. In addition, other courses designated CE have a significant engineering science component. Students can obtain information on these courses in consultation with their academic advisors.

Engineering design is the process of devising a system, component or process to meet desired needs. It is a decision-making process (often iterative) to convert resources to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. With the exception of those

CIVIL AND ENVIRONMENTAL ENGINEERING PROGRAM CHART

STUDENTS EARNING AN ABET ACCREDITED DEGREE IN CIVIL ENGINEERING MUST COMPLETE A MINIMUM OF 15 UNITS OF STUDY ARRANGED IN ACCORDANCE WITH THE DISTRIBUTION REQUIREMENTS. THIS CHART SUMMARIZES COURSE RECOMMENDATIONS– SEE YOUR ADVISOR TO DEVELOP YOUR PROGRAM SCHEDULE.

MATHEMATICS	SCIENCE †
4 Units Required	
MA1020/1021*	CH 1010
MA 1022*	CH 1020
MA 1023*	CH 1030
MA 1024	PH 1110
MA 2051*	PH 1120
MA 2071	PH 1130
MA 2210	BB 1001
MA 2611	GE 2341

NOTES

Basic math and science courses should be completed early in the curriculum, prior to taking many CE courses. Students may select from other math and science courses in addition to those listed here.

* Mathematics requirements include differential and integral calculus, and differential equations.

† Science: Must include both chemistry and physics with a minimum of two courses in either.

ENGINEERING SCIENCE AND DESIGN 6 Units Minimum Required (Minimum 4 Units in the Civil Engineering area as noted in Distribution Requirements)						
Fundamental Courses	CE 1030 (1), CE 2000 (1), CE 2001 (1), CE 2020 (3), ES 3004 (1), CE 3041					
Background Courses	CE 3030, ES 2503 (1), ES 3001 (1,2), EE 3601 (1,2)					
Area (4,5)	Structural	Geotechnical	Environmental and Hydraulics	Urban and Environmental Planning	Transportation	Construction and Management
Breadth	CE 3010	CE 3041	CE 3059	CE 3070	CE 3050	CE 3020 (1)
Depth	CE 2002 CE 3006 CE 3008 CE 3026 (3) CE 4007 CE 4017	CE 3044 CE 4046 (3) CE 4048	CE 3060 CE 3061 CE 3062 CE 4060 (3) CE 4061	CE 3074 CE 4071	CE 3051 CE 3054 (3)	CE 3021 CE 3022 (1) CE 3023 CE 3024 (3) CE 4024
MQP	1 Unit Emphasizing Design (in area of choice) Should be completed in senior year and meet capstone design requirement.					

NOTES
1. Includes material covered on Fundamentals of Engineering General Exam.
2. Meets the requirement for at least one engineering science course outside of Civil Engineering.
3. Meets the requirement for appropriate laboratory experience (two laboratory courses required).
4. To demonstrate breadth, students must select courses from a minimum of four areas. Courses should also be selected to demonstrate depth in at least one area.
5. Many areas are interrelated. See your advisor for information on depth courses that are related to your area of interest.

ADDITIONAL DEGREE REQUIREMENTS
4 UNITS REQUIRED

Social Science	2/3 Units
Humanities and Arts	2 Units (includes Sufficiency)
IQP	1 Unit
Physical Education	1/3 Unit

CE courses designated engineering science, all other CE courses are design courses or have a significant design component. Students can obtain information on these courses in consultation with their academic advisor. At least two units of engineering design consisting of appropriate civil engineering courses and the MQP are required as part of the ABET six-unit engineering science and design distribution requirement.

SUBAREAS OF CIVIL ENGINEERING

STRUCTURAL AND GEOTECHNICAL ENGINEERING

The practice of structural engineering involves the analysis and design of buildings, bridges and other structures which are generally a part of all civil engineering systems. Geotechnical engineering encompasses a broad spectrum of interests including the design, analysis and construction of foundations for buildings and other structures, highway embankments, dams and waste containment facilities. It also considers tunnels, ground water development and engineering in the ocean environment.

An educational program leading to preparation for a career in structural and geotechnical engineering must necessarily include in-depth studies in the basic sciences, mechanics of materials, structural analysis, and design, computer applications, and engineering properties of construction materials. The important courses in this area are CE 2002, CE 3010, CE 3006, CE 3008, CE 3044, CE 3026, CE 4046, CE 4048 and CE 4007. Structures generally are a part of large engineering projects and systems. A valuable component of an engineering education involves the interface with other engineering areas. Knowledge of subject matter contained in CE 3020, CE 3059, CE 3050 and CE 3070 is useful for the structural or geotechnical engineer. Major Qualifying Projects in this field often focus primarily on either structural or geotechnical aspects, although many projects integrate the two areas, in addition to construction project management. Representative recent MQP topics include comparative building design and integration of design and construction.

ENVIRONMENTAL ENGINEERING

Environmental engineering is that branch of civil engineering involved with environmental quality control. The practicing environmental engineer is concerned with planning, design, construction, operation and regulation of water quality control systems related to water supply and treatment, and waste water collection and treatment. The environmental engineer is also concerned with solid waste management, public health, radiological health, and air pollution control. The Civil Engineering Department at WPI emphasizes water quality aspects of environmental engineering. Key courses of this subarea are CE 3004, CE 3059, CE 3060, CE 3061, CE 3062, and CE 3074. Further depth in this field can be obtained by taking CE 4060, CE 4048, CE 4061 and other appropriate courses in chemistry, biology and biotechnology, chemical engineering, and fluid mechanics. The student should attempt to obtain some social science background, particularly in economics and possibly in law. Other engineering areas will enhance the environmental component of large projects. Courses such as CE 3010, CE 3020, CE 3050 and CE 3070 will be helpful. Recent MQP topics have focused on multimedia contaminant transport, pollution prevention, water quality issues, biosolids, and environmental impact.

TRANSPORTATION ENGINEERING

Transportation engineering is concerned with finding solutions to transportation problems such as designing and constructing safe, stable and durable pavement to carry large volumes of traffic vehicles that will be used in the 21st century. The highway infrastructure system in the US plays an important role in the commerce, economic development and security of the nation. These systems are deteriorating at a fast pace because of age, heavy increase in use and loading and deferred maintenance. While the highway infrastructure systems needs to be enhanced and maintained in order to provide the mobility needs of the nation, improvements must also be safe, efficient and environmentally benign.

A comprehensive set of courses is offered for providing both basic and in-depth knowledge in transportation engineering. The principal emphasis of transportation engineering at WPI is on traffic engineering, highway design, highway and roadside safety, principles of drainage and construction materials and pavement management. Students can gain basic understanding from breadth courses and in-depth knowledge about specific topics by taking depth courses. Breadth courses in this area are CE 3050 and CE 3026. Depth courses are CE 3051, and CE 3054 .

The transportation engineering sub-area offers a wide range of MQP topics, which involve practical application of design principles in solving real-world problems. Recent MQP topics include design of a field permeameter for pavements, development of a mix design system for recycled pavement mixes, design of durable asphalt pavement mixtures, a study of parking needs and options on the WPI campus, an analysis of traffic accidents in Worcester, an economic study of the pros and cons of having trees in highway medians and ride quality study.

URBAN AND ENVIRONMENTAL PLANNING

The principal emphasis of urban design at WPI is the spatial arrangement of sites, neighborhoods, communities and regions, expressed through comprehensive site and development plans. These show the recommended uses of land such as residential, business, industrial, and recreational. The preservation of open space is also a major concern.

Key courses of this subarea are CE 3070, CE 3074, and CE 4071. Further depth in this field can be obtained by taking CE 4046, CE 4048, and selected graduate courses. An understanding of the other engineering areas will enhance the urban design area. Courses such as CE 3010, CE 3059, CE 2020, CE 3026, and CE 4024 will be helpful. Recent MQP topics include highway route selection, highway environmental impact, design of residential area and design of new towns, and GIS applications to planning.

CONSTRUCTION ENGINEERING AND PROJECT MANAGEMENT

The civil engineering program in construction engineering and project management is directed to students whose interests lie in the design engineering process but who are also concerned with the problems in social science, management, business, labor and legal relations, and the interaction of governmental and private interests as they relate to major construction projects.

Because of the multidisciplinary nature of the program, students are encouraged to complete courses in management. Information and control systems are important to construction management, and competence in utilizing computers in these areas is expected. Students are encouraged to work with the profession through projects and other activities. Key courses in the area are CE 3006, CE 3008, CE 3020, CE 3021, CE 3022, CE 3023, CE 3024, CE 3030, and CE 4024. An understanding of other engineering areas will enhance a construction engineering and management program. Courses such as CE 3044, CE 3050, CE 4071, and CE 3059 will be helpful. Typical project topics include computers in construction, prefabricated buildings, rehabilitative construction strategies, scheduling of construction projects, cost evaluation of construction, and integration of design and construction.

MASTER BUILDER PROGRAM

INTRODUCTION

The civil engineering practice is undergoing significant, rapid and revolutionary changes, demanding a much higher level of knowledge and experience of new engineers than in previous generations. Today engineers must have skills in computer applications, information technology, management, communications and foreign languages, as well as fundamental engineering skills. They must also grasp the political economic and social implications of projects. Engineers must have an increased depth of knowledge of specialty areas and keep up with technological advances in methods and materials. A master's degree may become soon the first recognized professional degree leading to professional licensing.

The Master Builder Program is a new Masters of Engineering program created by the Department of Civil and Environmental Engineering to respond to the needs of the profession for the 21st Century. It has been designed within the context of WPI's project-based education and teamwork. It is available through the combined-degree program for those undergraduate students in the civil and environmental department that wish to accelerate their graduate work by careful development of their undergraduate plan of study leading to a B.S. degree and a M.E. degree in five years. The combined-degree requires 16 units for the completion of the B.S. degree. However, students can apply 12 credits counted toward the master's degree to be counted toward the bachelor's degree.

The Master Builder program has been designed to educate engineers with technical competency and management proficiency, able to effectively participate and play a leadership role in multi-disciplinary teams within the increasingly complex and demanding architectural/engineering/construction industry. These professionals are prepared to effectively integrate the planning, design construction and management of constructed facilities. They should be able to work for clients such as private developers and public agencies, traditional design, construction and facilities management firms as well as with integrated design-build firms.

COMBINED-DEGREE PROGRAM FIVE-YEAR PROGRAM

High school seniors can be admitted to the combined-degree Master Builder Program as freshman, allowing them to complete both a bachelors of science and master of engineering degree in civil and environmental in five years.

GRADUATE INTERNSHIPS AND CO-OP PROGRAM

A unique graduate internship program is available, allowing students to gain important clinical experiences in a practical engineering and research environments. Students are able to earn income, alternating work and on-campus classroom and laboratory activities.

PROJECTS

A great variety of projects are available to civil and environmental engineering students. Students should select project topics which are related to their subarea of emphasis. Project work is an extremely important part of civil engineering education, and the WPI Plan provides an excellent opportunity to strengthen this aspect of undergraduate education. Project activities are a combination of design, sponsored research, laboratory investigations, field work, and internship activities with governmental agencies and private industry. Students may become involved in project work at an early stage of the education program, and should have some Major Qualifying Project activity either under way or well in mind by the end of the junior year. The objectives of such work should include the development of the student's ability to analyze comprehensive situations, consider alternative solutions, define key problems, pick out major variables, and estimate orders of magnitude for reaching decisions. A major objective is the development of sound judgment and skill, incorporating engineering economics and social factors into problem solving.

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

INFORMATION FOR NONMAJORS

Students from other departments find certain civil engineering courses to be valuable in the construction of their individual programs. The specific courses to be taken depend upon the interest of each student. CE 2000, CE 2001, CE 3010, and CE 3041 are useful if the student's program has a need for structures and geotechnical background. CE 3059, CE 3060 and CE 3061 are good courses for students interested in water quality control. Other courses of interest to nonmajors in this field are CE 3062 and CE 4061. CE 2020, CE 3050, CE 3051, CE 3070, and CE 3074 are valuable to students interested in transportation and urban and environmental planning. For students interested in construction engineering and management, the key courses are CE 2020, CE 3020, CE 3021, CE 3022, and CE 3023.

In addition to courses, the Civil and Environmental Engineering Department offers project opportunities for nonmajors as part of a project team.

PROGRAM DEVELOPMENT

The development of broad goals with an advisor is an important early step in the construction of a cohesive educational program that has substantial opportunity for flexibility and changes throughout the undergraduate association at WPI. The program will include mathematics, basic sciences, social sciences, humanities and arts sufficiency, physical education, and engineering science and design. The civil engineering advisors are listed below, organized in the general areas of interests. All of the advisors are available to provide counsel for either specific or general civil engineering programs.

CIVIL ENGINEERING AREA CONSULTANTS

Structural and Geotechnical Engineering
L. Albano
R. D'Andrea
T. El-Korchi
R. Fitzgerald
P. Jayachandran

Environmental Engineering
J. Bergendahl
M. FitzPatrick
F. Hart
P. Mathisen
J. O'Shaughnessy
J. Plummer

Transportation and Urban Planning
T. El-Korchi
M. FitzPatrick
R. Mallick
M. Ray

Construction Engineering and Management
L. Albano
R. D'Andrea
R. Fitzgerald
R. Pietroforte
G. Salazar

The civil engineering part of the program has requirements, although no unique courses are specifically required to complete the program. Nevertheless, certain courses normally are considered a part of a civil engineering education, unless a strong basis for deviation exists. Consultation with an advisor will help an individual to construct a program that both meets WPI and ABET requirements and also provides a breadth and professional training in areas of interest. To provide guidance in structuring a program, the following courses normally should be considered as a basic expectation for all civil engineering programs:

CE 1030	Fundamentals of Computers and Civil Engineering	I
CE 2000	Analytical Mechanics I	I
CE 2001	Analytical Mechanics II	I
ES 3004	Fluid Mechanics	I
CE 2020	Surveying	I
CE 3041	Soil Mechanics	I

The following courses should be considered as fundamental to most civil engineering programs:

CE 2002	Introduction to Analysis and Design	I
CE 3026	Materials of Construction	I
CE 3030	Fundamentals of Civil Engineering AutoCAD	I

The courses listed below are designed to develop a professional base for more advanced work in the specialty areas, as well as to provide a terminal knowledge for students who wish to select areas of concentration in other disciplines. Student programs should include as many of these courses as possible to provide a breadth of understanding across the major civil engineering disciplines.

CE 3010	Structural Engineering	I
CE 3020	Project Management	I
CE 3059	Environmental Engineering	I
CE 3070	Urban and Environmental Planning	I

A cohesive program should include a selection of courses in the professional areas noted below. The student should incorporate courses in as many areas as practicable to develop a program that has both substance and breadth. Many of the courses have interactive applications in two or more engineering disciplines.

Construction Engineering and Management		**Category**
CE 3021	Cost Estimating, Scheduling, and Cost Control	II
CE 3022	Legal Aspects in Design and Construction	II
CE 3023	Architectural Engineering Systems	I
CE 3024	Control Surveying	II
CE 4024	Real Estate Development	II
Environmental Engineering		
CE 3060	Water Treatment	I
CE 3061	Waste Water Treatment	I
CE 3062	Hydraulics in CE	I
CE 4060	Environmental Engineering Lab	I
CE 4061	Hydrology	I
Geotechnical Engineering		
CE 3044	Foundation Engineering	I
CE 4046	Experimental Soil Mechanics	II
CE 4048	Earth Strucures	II

Structural Engineering

CE 3006	Design of Steel Structures	I
CE 3008	Design of Reinforced Concrete Structures	I
CE 4007	Matrix Analysis of Structures	I
CE 4017	Prestressed Concrete Design	I

Transportation and Planning

CE 3050	Highway Engineering and Planning	I
CE 3051	Introduction to Pavement Materials Design and Management	I
CE 3054	Asphalt Technology	I
CE 3070	Urban and Environmental Planning	I
CE 3074	Environmental Analysis	I
CE 4071	Land Use Development and Controls	I

ENVIRONMENTAL ENGINEERING

Civil/Environmental Engineering with Emphasis on Water Quality Control

COORDINATORS: Profs. O'Shaughnessy, Mathisen, Hart, Plummer, or Bergendahl

The Department of Civil and Environmental Engineering at WPI provides courses leading to an ABET-accredited degree in Civil Engineering. Areas of emphasis include: the planning, design, construction, operation, and regulation of water quality control systems related to water supply and waste treatment. Environmental areas also include: public health, water supply, waste minimization treatment, and management. The engineering focus is in the area of large systems associated with municipal and other public projects.

At the undergraduate level, students often complete study in the areas of hydrology, hydraulics, hydrogeology, water supply, wastewater treatment, environmental analysis, and hazardous waste management. These areas are evaluated using physical, chemical, and biochemical techniques.

In addition to municipal and regional approaches covered in most courses, many MQP projects focus on industrial environmental problems. Typical problems include: ground water and soil contamination, waste minimization, water quality, biosolids, and hazardous waste management.

Students majoring in this program would follow a general curriculum in Civil and Environmental Engineering, with emphasis on the environmental engineering subarea. Such preparation leads to a degree recognized by the professional accrediting organization, ABET (Accreditation Board of Engineering and Technology), and is an excellent start for entry-level professional placement or graduate study in environmental engineering.

COMPUTER SCIENCE

M. HOFRI, HEAD; L. A. BECKER, ASSOCIATE HEAD

PROFESSORS: D. C. Brown, D. Dougherty, D. Finkel, M. Hofri, S. M. Selkow, M. O. Ward

ASSOCIATE PROFESSORS: L. A. Becker, M. A. Gennert, N. I. Hachem, R. E. Kinicki, K. A. Lemone, E. A. Rundensteiner, C. E. Wills

ASSISTANT PROFESSORS: E. Agu, M. Claypool, K. Fisler, N. Heffernan, G. T. Heineman, C. Ruiz

PROFESSOR OF PRACTICE: M. Ciaraldi

AFFILIATED ASSOCIATE PROFESSOR: G. N. Sarkozy

ASSOCIATE RESEARCH PROFESSOR: F. C. Osorio

INSTRUCTORS: V. Dobrushkin, G. Hamel

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 lifelong learning.

GOALS

The goals of the WPI Computer Science Program are to:

1. Prepare students to function professionally as computer scientists and software engineers.
2. Prepare students for graduate studies in computer science and related disciplines.
3. Develop in students critical thinking and problem-solving skills.
4. Prepare students to assume responsible positions in society.
5. Prepare students for life-long learning.
6. Foster in students a sense of ethical behavior and respect for diversity.

OBJECTIVES

The objectives established by the WPI Computer Science Program in support of its goals and mission are to graduate students with a Computer Science major who:

1. Are prepared technically for computer science and software engineering practice.
2. Understand the basic principles of computer science and software engineering.
3. Understand appropriate mathematical concepts and are able to apply them to computational problems.
4. Have knowledge of computer hardware and architecture.
5. Understand and follow the software engineering process.
6. Are prepared to design and implement software systems.
7. Are prepared to analyze and evaluate software systems.

8. Understand fundamental scientific principles and the scientific method.
9. Can function effectively in diverse teams and situations.
10. Can communicate effectively in speech and in writing.
11. Are able to learn independently and find relevant resources.
12. Are prepared for future changes in computer science and software engineering.
13. Are prepared to uphold professional and ethical standards.
14. Understand and appreciate the role of computer science and software engineering in a societal context.
15. Are aware of career and further educational opportunities.
16. Have a mature understanding of themselves and others.

OUTCOMES

Based on the above objectives, the specific outcomes to be achieved for the WPI Computer Science major are that:

1. All students will demonstrate an understanding of programming language concepts.
2. All students will demonstrate knowledge of computer organization.
3. All students will demonstrate an ability to analyze the behavior of computational systems.
4. All students will demonstrate knowledge of computer operating systems.
5. All students will demonstrate an understanding of the foundations of computer science.
6. Almost all students will demonstrate an understanding of software engineering principles and the ability to apply them to software design.
7. A majority of students will demonstrate an understanding of human-computer interaction.
8. All students will complete a large-scale software project.
9. All students will demonstrate advanced knowledge of computer science topics.
10. All students will demonstrate an understanding of the mathematical foundations of computer science.
11. All students will demonstrate knowledge of probability or statistics.
12. All students will demonstrate an understanding of scientific principles.
13. A majority of students will demonstrate the ability to design experiments and interpret experimental data.
14. All students will demonstrate independent learning.
15. All students will demonstrate the ability to locate and use technical information from multiple sources.
16. All students will demonstrate an understanding of professional ethics.
17. All students will demonstrate an understanding of the links between technology and society.
18. A majority of students will belong to at least one professional organization, including IEEE, ACM, and UPE.
19. All students will participate in a class or project team.
20. Almost all students will demonstrate the ability to communicate effectively in speech.
21. All students will demonstrate the ability to communicate effectively in writing.

INTRODUCTION

Computer scientists should be broadly-educated individuals with a clear understanding of the natural laws and social orders that govern the world around them.
Well-educated individuals in our technical society must be knowledgeable in the areas of mathematics, humanities and social science, science, and engineering. Therefore, a student's program of study should include in-depth studies in several disciplines in addition to computer science. Broad-based education cannot be mandated by simply listing courses or topics to be studied. Instead, the WPI Plan encourages an integration of formal course work, project activity, self-study, and personal experiences. We cannot urge strongly enough that students make the very best use of the diverse educational opportunities available to them.

To be effective in business and society, computer scientists must be able to do more than design computing systems. They must relate to and communicate with people, so as to apply these systems to improving real- life situations. In recognition of the need for technical specialists who also have human-oriented skills, the WPI Plan requires a strong background in the humanities. To ensure breadth within the broad discipline of computer science and a firm grounding in mathematics and science, a student must complete the department's program distribution requirements.

The major designated as "Computer Science" is the only program accredited by the Computing Accreditation Commission of ABET within the Department of Computer Science.

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 22) 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 computer science courses at the 2000-level or higher will 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 4514, CS 4515), Theory and Languages (CS 3133, CS 4123, CS 4533), Design (CS 3041, CS 3431, CS 3733, CS 4233), and Social Implications of Computing (CS 3043, SS 2208, SS/ID 2314). (If SS 2208 or SS/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, with the exception of CS 501 and CS 507.
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, BE, CE, CH, CM, EE, ES, GE, ME, PH disciplines. At least three courses must come from BB, CH, GE, PH, where at least two courses are from one of these disciplines.
5. At most four 1000-level Mathematics courses may be counted towards this requirement.

The Computer Science Department offers a second program not accredited by the Computing Accreditation Commission of ABET and not bearing the title "Computer Science." The distribution requirements for that program are:

Program Distribution Requirements for the Computers with Applications Major

COMPUTERS WITH APPLICATIONS	Minimum Units
1. Computer Science (including the MQP) (Notes 1, 2).	16/3
2. Mathematics (Note 2).	7/3
3. Basic Science (Notes 2, 3).	2/3
4. Application Area (Notes 2, 4).	5/3

NOTES:

1. a. Only computer science courses at the 2000-level or higher will 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 4514, CS 4515), Theory and Languages (CS 3133, CS 4123, CS 4533), Design (CS 3041, CS 3431, CS 3733, CS 4233), and Social Implications of Computing (CS 3043, SS 2208). (If SS 2208 is used to satisfy this requirement, it does not count as part of the 16/3 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, with the exception of CS 501 and CS 507.
   d. The MQP must involve the application of computer science concepts to the Application Area specified in Requirement 4.
2. A cross-listed course may be counted toward only one of areas 1, 2, 3, 4 above.
3. The two courses satisfying the science requirement must both come from one of the following disciplines: BB, CH, GE, PH.
4. This requirement is satisfied by a cohesive set of work from disciplines other than Computer Science. Work used for any other degree requirements cannot be used for the Application Area. At least 3/3 units must be course work at the 3000 level or higher. Independent Study/Project (ISP) work, if any, must be conducted under the supervision of a member of the faculty in that discipline.

PREVIOUS DISTRIBUTION REQUIREMENTS FOR COMPUTER SCIENCE AND COMPUTERS WITH APPLICATIONS MAJOR

The above distribution requirements apply to all students whose matriculation date is after May 1, 2003. Students who matriculated prior to May 1, 2003 should consult the catalog for their year of entry or consult with their academic advisor or the Chair of the Department Distribution Review Committee.

PLANNING A COMPUTER SCIENCE MAJOR

Computer science students, upon completion of their program of study, should have developed a number of areas of competence. This competence is a blend of practical skills and knowledge of applied techniques and theoretical concepts. "Core" courses in computer science provide a foundation in the areas of programming, data structures, computer organization and operating systems, mathematics and theoretical computer science, and the social impact of computing.

The ability to program is a major practical skill to develop. This is fundamental, of course, to the application of computers for any purpose whatsoever. Programming is not a mere synonym for coding. It includes a skillful evaluation of the problem statement, the development of an efficient algorithm and data structure for the solution of the problem, a clear specification of the algorithm and data structure, an evaluation of the cost of executing the algorithm, the actual coding, and the creation of sufficient test cases to verify the accuracy of the solution. The student must develop a strong programming ability in at least one high-level language as well as an ability to program in an assembler language.

The efficient organization of data into structures of varying complexity is an important part of the solution to most programming problems. Students must study not only the theoretical aspects of such structures but also their applications. In addition, students must become familiar with the techniques of representing various structures within the limitations imposed by the memory and languages available on the computer.

Students should have a clear understanding of the fundamental processes that occur within a general-purpose computing system. Familiarity with the operation of the hardware should be developed, as well as knowledge of the way hardware, operating systems, and user programs interact to form an effective computing system.

The theoretical aspects of computer science depend upon discrete mathematics for their description, so computer scientists should be familiar with this area of mathematics and how it relates to computer science theory.

In today's society the computer is a tool which affects the lives of everyone. The computer scientist cannot, in good conscience, remain blissfully ignorant of the impact caused by his or her own decisions and actions. Therefore, the computer science student is urged to study the relation between individuals, society and the computer.

Majors in computer science should be familiar with material in the following areas, although students are not required to take all of these.

CORE COURSES FOR MAJORS IN COMPUTER SCIENCE

Computer Science

CS 1005	Introduction to Programming
CS 1006	Object-Oriented Introduction to Programming
CS 2005	Techniques of Programming
CS 2011	Introduction to Machine Organization and Assembly Language
CS 2022	Discrete Mathematics
CS 2135	Programming Language Concepts
CS 2136	Paradigms of Computation
CS 2223	Algorithms
CS 3013	Operating Systems
CS 3041	Human-Computer Interaction
CS 3043	Social Implications of Information Processing
CS 3133	Foundations of Computer Science
CS 3733	Software Engineering

Mathematics
MA 1021 Calculus I
MA 1022 Calculus II
MA 1023 Calculus III
MA 1024 Calculus IV
MA 2071 Matrices and Linear Algebra I
MA 2611 Applied Statistics I
MA 2621 Probability

Note that other mathematics courses, such as MA 2051, may be useful background for advanced Computer Science courses.

For students who wish to improve their communication skills, the following courses are recommended: IS 1811, Writing for International Students, IS 1812, Speech for International Students, or EN 2211, Elements of Writing.

There is one noncore language course available. CS 1001, Introduction to Computers, teaches programming using FORTRAN, which has been used in engineering and scientific programming.

ADVANCED COURSES IN COMPUTER SCIENCE

After students have established a firm foundation in computer science, they should explore advanced topics, leading toward MQP work. Students must take at least one course from each of the following areas: Systems (CS 3013, CS 4513, CS 4514, CS 4515), Theory and Languages (CS 3133, CS 4123, CS 4533), Design (CS 3041, CS 3431, CS 3733, CS 4233), and Social Implications of Computing (CS 3043, SS 2208, SS/ID 2314). Other 4000-level courses may be divided among these areas or concentrated in a particular area according to each student's program objectives. The diagram on page 98 indicates how the material presented in each course is used by subsequent courses. Some variation in course order may occur, but the student considering taking courses out of sequence is advised to check the course descriptions for recommended background.

COMPUTER SCIENCE PROGRAM CHART

COMPUTER SCIENCE
Minimum 18/3

CORE COURSES
CS 2005, CS 2011, CS 2022, CS 2135, CS 2136, CS 2223, CS 3013, CS 3041, CS 3043, CS 3133, CS 3733

SYSTEMS —Minimum 1/3
CS 3013, CS 4513, CS 4514, CS 4515

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

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

SOCIAL IMPLICATIONS—Minimum 1/3
CS 3043, SS 2208, SS/ID 2314
SS 2208, SS/ID 2314 do not count toward the 18/3 CS units

ADVANCED LEVEL COURSES—Minimum 5/3

COMPUTER SCIENCE MQP—Minimum 3/3

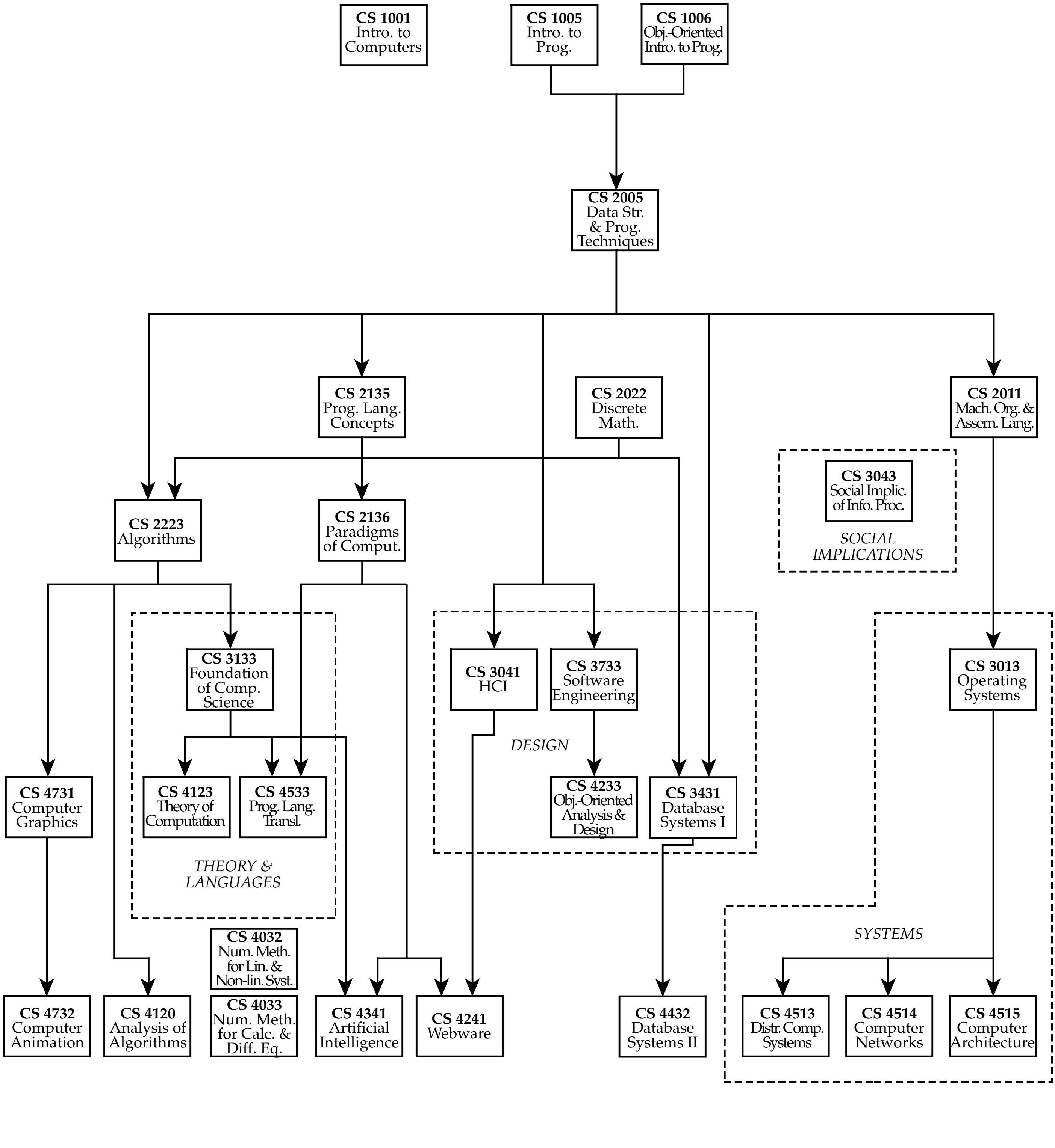
SCIENCE
Minimum 5/3
Any BB, BE, CE, CH, CM, EE, ES, GE, ME, PH courses.
At least three courses must come from BB, CH, GE, PH, where at least two courses are from one of these disciplines.

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

STATISTICS—Minimum 1/3
MA 2611, MA 2612

PROBABILITY—Minimum 1/3
MA 2621, MA 2631

COMPUTER SCIENCE COURSE FLOW CHART



Listed below are several areas of computer science in which the student may wish to specialize, including some courses from other departments. These areas are meant to be illustrative; one should choose the course of study that best meets one's own needs and plans.

Operating Systems

CS 3013	Operating Systems
CS 4513	Distributed Computing Systems
CS 4514	Computer Networks: Architecture and Implementation
CS 4515	Computer Architecture
MA 2051	Ordinary Differential Equations
MA 2621	Probability for Applications

Software Systems

CS 3041	Human-Computer Interaction
CS 3431	Database Systems I
CS 3733	Software Engineering
CS 4233	Object Oriented Analysis and Design
CS 4241	Webware

Human-Computer Interaction

CS 3013	Operating Systems
CS 3041	Human-Computer Interaction
CS 3043	Social Implications of Information Processing
CS 3431	Database Systems I
CS 3733	Software Engineering
CS 4241	Webware: Computational Technology for Network Systems
CS 4341	Introduction to Artificial Intelligence
CS 4432	Database Systems II
CS 4731	Computer Graphics

Languages And Compilers

CS 3041	Human-Computer Interaction
CS 3133	Foundations of Computer Science
CS 3733	Software Engineering
CS 4233	Object-Oriented Analysis and Design
CS 4533	Techniques of Programming Language Translation

Theoretical Computer Science

CS 3133	Foundations of Computer Science
CS 4120	Analysis of Algorithms
CS 4123	Theory of Computation
CS 4533	Techniques of Programming Language Translation
MA 2271	Graph Theory
MA 2273	Combinatorics
MA 4631	Probability and Mathematical Statistics I

Scientific Applications

CS 4032	Numerical Methods for Linear and Non-linear Systems
CS 4033	Numerical Methods for Calculus and Differential Equations
CS 4731	Computer Graphics
MA 1021	Calculus I
MA 1022	Calculus II
MA 1023	Calculus III
MA 1024	Calculus IV
MA 2051	Ordinary Differential Equations
MA 2621	Probability for Applications
MA 3231	Linear Programming
MA 4411	Numerical Analysis of Differential Equations
PH 1110	General Physics — Mechanics
PH 1120	General Physics — Electricity and Magnetism

Hardware Orientation

CS 4515	Computer Architecture
EE 3601	Principles of Electrical Engineering
EE 3801	Advanced Logic Design
EE 3803	Microprocessor System Design
EE 3815	Digital System Design with VHDL
EE 4801	Advanced Computer System Design

Students who are interested in the hardware aspects of computers, yet do not need a strong background in electronics, may omit the introductory electrical engineering courses and begin with EE 3801. Such a decision should be discussed with one's academic advisor.

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 qualifying projects are available at the Silicon Valley Project Center, the NASA/Goddard Space 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 including assistance with, and development of, computer science education at neighboring area schools.

COMBINED BACHELOR'S/MASTER'S PROGRAM

Computer Science majors are advised to investigate the opportunity to enroll in the Combined Bachelor's/ Master's Program described on page 242. For application information, consult the CS department office.

COMPUTER SCIENCE FOR THE NONMAJOR

A knowledge of at least one programming language is virtually essential to professionals in most disciplines. The computer science faculty recommends that all WPI students give serious consideration to one or more of these introductory computer language courses:

CS 1001	Introduction to Computers
CS 1005	Introduction to Programming
CS 1006	Object-Oriented Introduction to Programming
CS 2005	Techniques of Programming

Most students will need to program in a general purpose language, and therefore will elect to take either CS 1001 to study Fortran or CS 1005 to study the C programming language or CS 1006 to study the Java programming language. Fortran is an older language that was developed for scientific programming requiring arithmetic computations. Current versions of Fortran are suitable for general purpose programs. Consult your academic advisor on whether to learn Fortran, or C, or Java.

Students having a strong interest in computer science should begin their course work in computer science with CS 1005 and CS 1006; these courses provide a rigorous introduction to programming. Either CS 1005 or CS 1006 may be followed by CS 2005. Students who develop interest in computer science after taking CS 1001 are urged to consider taking CS 1005 or CS 1006, followed by CS 2005.

Nonmajors choosing an introductory computer science course are advised to consult with their academic advisor. Also be aware that certain departments have specific recommendations for their majors.

Students who plan to make frequent use of computers in their chosen fields are urged to begin their studies with CS 1005 or CS 1006, followed by CS 2005, and should consider pursuing a minor in Computer Science. The Computer Science minor is described below.

COMPUTER SCIENCE MINOR

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

CS 3013 Operating Systems
CS 3041 Human-Computer Interaction
CS 3133 Foundations of Computer Science
CS 3431 Database Systems I
CS 3733 Software Engineering
CS 4120 Analysis of Algorithms
CS 4123 Theory of Computation
CS 4233 Object-Oriented Analysis and Design
CS 4241 Webware: Computational Technology for Network Systems
CS 4341 Introduction to Artificial Intelligence
CS 4432 Database Systems II
CS 4513 Distributed Computing Systems
CS 4514 Computer Networks: Architecture and Implementation
CS 4533 Techniques of Programming Language Translation
CS 4731 Computer Graphics

- any graduate-level CS course, except for CS501, CS505, CS507, CS552, or CS590
- 1/3 unit of another activity, for example an ISP, which is validated by a CS faculty member as a capstone.

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

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

EE majors and Management Information Science majors should review the Operational Rules of the Minor at WPI to avoid problems with double counting CS courses. For general policy on the Minor, see the description on pages 26-27.

ELECTRICAL AND COMPUTER ENGINEERING

J. A. ORR, HEAD; F. J. LOOFT, ASSOCIATE HEAD
PROFESSORS: K. A. Clements, D. Cyganski, A. E. Emanuel, F. J. Looft, R. Ludwig, J. A. Orr, K. Pahlavan, E. A. Parrish, Jr., P. C. Pedersen
ASSOCIATE PROFESSORS: R. J. Duckworth, H. Hakim, S. Makarov, J. A. McNeill, W. R. Michalson, R. F. Vaz
ASSISTANT PROFESSORS: D. R. Brown, E. A. Clancy, B. King, D.P. Papageorgiou, B. Sunar, N. Whitmal
PROFESSOR OF PRACTICE: R. Labonte
ADJUNCT PROFESSOR: R. H. Campbell
INSTRUCTOR: S. J. Bitar, A. Hatami
EMERITUS PROFESSORS: J. S. Demetry, W. H. Eggimann, W. R. Grogan, O. W. Kennedy, H. P. D. Lanyon, A. K. McCurdy, G. H. Owyang, G. E. Stannard

INTRODUCTION

Since the invention of the transistor in 1947, the field of electrical and computer engineering (ECE) has seen tremendous and continuous growth. From its origins in electric power, the field now ranges from various analog and digital design disciplines to all forms of communication and signal processing systems. Working engineers design the components and systems that, for example: compose computers, computer networks and the Internet; control automobiles, aircraft and shipping vessels; monitor patient vital signs in medical critical care; provide secure and reliable wireless connectivity for telephones and electronic commerce; deliver electricity to our homes and work places; etc.

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.

EDUCATIONAL OBJECTIVES OF ECE DEPARTMENT PROGRAMS

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

MAJORS OFFERED

In the electrical and computer engineering department we currently offer the Bachelor of Science degree in two majors: *Electrical and Computer Engineering* (ECE) and *Electrical Engineering* (EE). The ECE major is new to the department, and was designed to offer greater breadth across the many subdisciplines of ECE. The EE major is the traditional program offered by the department, and includes an optional concentration in Computer Engineering. In the future, we intend to phase out the older EE program, eventually offering only the ECE major.

For either major, students must fulfill the general requirements set forth by WPI (such as the IQP and Sufficiency projects) as well as a set of department-specific "distribution requirements" in order to graduate The requirements stipulated by the ECE department apply to 10 units of study (out of the 16 units total that a typical student spends at WPI). They differ slightly according to the type of major desired (either ECE or EE). The following sections provide further description of the two majors and their respective distribution requirements. The EE major is accredited by the Accreditation Board for Engineering and Technology (ABET); the ECE major is new and will be considered for ABET accreditation at the earliest opportunity.

BACHELOR OF SCIENCE IN ELECTRICAL AND COMPUTER ENGINEERING

In recent years, the role of computers in electrical engineering has continued to grow. The use of computers has become an essential part of the analysis, design, and implementation of nearly all electrical engineering applications, and as a result, knowledge of computers and computer engineering has become a necessity for any successful electrical engineer. We believe that for any student to be skilled and successful in any area of ECE—whether entering the work force or continuing into graduate education—it is necessary that he or she possess a complete understanding of the fundamentals across the breadth of electrical and computer engineering. For these reasons, we recently created a new program that places greater emphasis on attaining a breadth of knowledge across the many sub-disciplines of ECE, particularly by incorporating a more complete balance between computer engineering and other areas of ECE. The ECE major will be evaluated for accreditation by ABET at the earliest opportunity.

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

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

Program Distribution Requirements for the Electrical and Computer Engineering Major

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

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

NOTES:

1. Mathematics and Basic Science:
   1a. Must include at least 7/3 units of math (prefix MA). Mathematics must include differential and integral calculus, differential equations, and probability and/or statistics.
   1b. Must include at least 2/3 units of physics (prefix PH).
   1c. Must include at least 1/3 units of chemistry (prefix CH) or 1/3 units biology (prefix BB).
   1d. 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):
   2a. Must include at least 5 units within the Electrical and Computer Engineering area (including the MQP). All courses with prefix EE (except EE 3601) are applicable to these 5 units. Also, courses ES 3011, BE 4011, and BE 4201 are applicable to these 5 units.
   2b. The 5 units within the Electrical and Computer Engineering area must include at least 1 unit of courses from an approved list of Electrical Engineering courses (listed in the Electrical and Computer Engineering Department and Program Description section of this catalog)
   2c. The 5 units within the Electrical and Computer Engineering area must include at least 2/3 unit of courses from an approved list of Computer Engineering courses (listed in the Electrical and Computer Engineering Department and Program Description section of this catalog)
   2d. 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.)
   2e. 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).
   2f. Must include at least 1/3 unit of engineering science (prefix ES) at the 2000 level or above. This requirement may also be satisfied by ME 3601. ES 3011 cannot be applied to this requirement.
   2g. Must include an additional 1/3 unit of engineering science and design at the 2000 level or above, selected from courses having the prefix BE, CE, CM, CS (other than CS 2011, CS 2022, CS 3043), EE, ES, FP, ME, or NE.

Electrical Engineering courses satisfying requirement 2b: EE 2112, 2201, 2312, 3113, 3204, 3305, 3306, 3311, 3501, 3503, 3703, 3711, 3901, 4304, 4502, and 4902; BE 4011 and 4201; and ES 3011.

Computer Engineering courses satisfying requirement 2c: EE 2801, 3801, 3803, 3815, 3902 and 4801.

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

The electrical engineering major has traditionally been the only one offered by the ECE department. It currently includes an optional concentration in Computer Engineering. We will continue to offer the EE degree until the ECE degree is accredited, after which point it will no longer be available to incoming classes. Note that even after the EE degree is phased out, any student who matriculated during the time it was still offered retains the option to graduate under its requirements. However, we do encourage all students to consider switching to the new ECE degree.

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

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

Program Distribution Requirements for the Electrical 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 major designated "Electrical Engineering" must satisfy certain distribution requirements. These requirements apply to 10 units of study in the areas of mathematics, basic science, and engineering science and design as follows:

Requirements	Minimum Units
1. Mathematics and Basic Science (Notes 1, 2, 3, 4).	4
2. Engineering Science and Design (ES/D) (including the MQP) (Notes 5, 6, 7).	6

NOTES:

1. Basic Science courses have prefixes PH, CH, BB, and GE.
2. Mathematics must include differential and integral calculus and differential equations.
3. Must include at least 1/3 chemistry and 2/3 physics or 2/3 chemistry and 1/3 physics.
4. Must include at least 7/3 units of math.
5. The six units of Engineering Science and Design must include at least two courses outside the major area and may include as many as three. All three courses must be at the 2000-level or above. One course requirement must be satisfied by ME 3601 or any course with prefix ES (other than ES 3011). The second course must have the prefix CS (other than CS 2011, CS 2022, CS 3043). If a third course is chosen that does not have the prefix EE, it must be selected from courses having the prefix BE, CE, CM, CS, (other than CS 2011, CS 2022, CS 3043), ES, FP, ME.
6. Must include at least 5 units within the Electrical and Computer Engineering area (including the MQP). All courses designated EE (except EE 3601) are applicable to these 5 units. Also, courses ES 3011, BE 4011, and BE 4201 are applicable to these 5 units.
7. Must include 1/3 unit of Capstone Design Experience.

These distribution requirements in Electrical Engineering apply to all students matriculating at WPI after May, 2003. Students who matriculated prior to May, 2003, have the option of satisfying the distribution requirements in the catalog current at the time of their matriculation.

CONCENTRATION IN COMPUTER ENGINEERING

Within the electrical engineering major, students interested in pursuing a concentration in computer engineering can do so by completing a set of activities as described below. Successful completion results in a B.S. degree in Electrical Engineering with the designation "with concentration in Computer Engineering" noted on the transcript if requested by the student from the Registrar.

This interdisciplinary concentration requires students to develop technical competence in mathematics, basic science, and electrical engineering, with further emphasis in computer engineering, including computer system design, high level languages and operating systems. The Major Qualifying Project provides students with the opportunity to develop in-depth knowledge of some aspect of computer engineering.

In order to be eligible to receive the Computer Engineering designation on their transcripts, students need to satisfy the following course requirements:

- At least six computer engineering related EE or CS courses must be included in the distribution requirements, as follows:
  - At least three of the following EE courses must be included:
    - EE 3803 Microprocessor System Design
    - EE 3815 Digital System Design with VHDL
    - EE 4801 Advanced Computer System Design
    - EE 3902 Introduction to VLSI Design
    - EE 505 Computer Architecture (or CS 4515 Computer Architecture, but not both).
  - At least two 3000 or 4000 level CS courses must be included; CS 3043, Social Implications of Information Processing, cannot be used. The following are particularly recommended:
    - CS 3013 Operating Systems
    - CS 3733 Software Engineering
    - CS 4513 Distributed Computer Systems
    - CS 4514 Computer Networks
    - CS 4515 Computer Architecture (or EE 505 Computer Architecture, but not both).
- In addition to the above course requirements, students must complete an MQP in the computer engineering area approved by the Program Coordinator.

DIFFERENCES BETWEEN THE EE AND ECE MAJORS

The differences between the distribution requirements for the traditional EE major and the new ECE major are fairly modest; many students will find that their programs satisfy both sets of requirements. The primary difference is that the requirements for the ECE major ensure that students achieve greater breadth of knowledge across the discipline than is required by the EE major. The total number of credits in the distribution requirements is the same, as are the numbers of required credits in mathematics and basic science, computer science, and engineering.

The specific differences are:

- ECE majors are required to take at least two courses that focus on computer engineering, and at least three courses that focus on electrical engineering, beyond the basic core level.
- ECE majors must include a course on probability or statistics.
- The minimum basic science requirement for ECE majors is 2/3 units of physics and 1/3 unit in either biology or in chemistry.
- The ECE major does not have any concentration options.

OVERVIEW OF ECE PROGRAM COMPONENTS

The path toward a degree in the ECE Department varies greatly from student to student. To be successful, you must tailor your program to fit your academic needs, working within the boundaries of the major's distribution requirements and WPI's general degree requirements.

This section is intended as a guide to clarify the program components you will need to fulfill the distribution requirements for both ECE and EE majors. It also contains information about general WPI requirements, and advice on how to integrate these elements into your degree plan.

MAJOR QUALIFYING PROJECT (MQP)

In many cases, the pinnacle of a student's undergraduate work at WPI is the MQP, the senior-level design project. Both the ECE and EE degrees require all students to complete an MQP worth 1 unit of study in the major area (the equivalent of 3 courses). Note that this 1 unit is part of the 6 total needed to fulfill the "Engineering Science and Design" distribution requirement. Of the remaining 5 units, 4 units (12 courses) are met by courses in the major area. The breakdown of courses needed is discussed further in the section titled "Other ECE Department Course Work."

Also note that projects that lack a significant engineering design component are typically not approved. Thus, the 1/3 unit of "Capstone Design Experience" required for both ECE and EE majors is almost always a part of the MQP, and need not be fulfilled by a separate course.

The MQP is an extremely important part of your degree program: it is a single project that accounts for the equivalent of three ECE-related courses, and provides some of the most directly relevant preparation you will receive for graduate school or a job in industry. Your MQP can be very rewarding, exciting, and even fun. However, it can also be quite frustrating if you are not adequately prepared. Consequently, when planning your degree program, a good deal of effort should be made to ensure you have developed a solid foundation in all areas of ECE before attempting to begin your project.

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).

Power Systems Engineering
Area Consultants: Clements, Emanuel, Hakim

Area Courses
EE 3501 Electrical Energy Conversion
EE 3503 Power Electronics
EE 4502 Analysis of Large Scale Power Systems

Related Courses
ES 3001 Introduction to Thermodynamics
ES 3011 Control Engineering I
MG 2850 Engineering Economics
ME 1800 Materials Selection and Manufacturing Processing

RF Circuits and Microwaves
Area Consultants: Ludwig, Makarov

Area Courses
EE 2112 Electromagnetic Fields
EE 3113 RF Circuit Design

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

Aerospace and Control Systems
Area Consultants: Labonte, Michalson

Area Courses
EE 3305 Aerospace Avionics Systems
ES 3011 Control Engineering I

Related Courses
EE 2312 Discrete-Time Signal and System Analysis
EE 3204 Microelectronics II
EE 3311 Principles of Communication Systems
EE 3503 Power Electronics
EE 3801 Advanced Logic Design
EE 3803 Microprocessor System Design
EE 4304 Communication Systems Engineering

Communications and Signal Analysis
Area Consultants: Brown, Clancy, Cyganski, Hakim, King, Looft, Makarov, Orr, Pahlavan, Pedersen, Sunar, Vaz, Whitmal

Area Courses
EE 2312 Discrete-Time Signal and System Analysis
EE 3311 Principles of Communication Systems
EE 3703 Real-Time Digital Signal Processing
EE 3711 Introduction to Electro-Optics
EE 4304 Communication Systems Engineering

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

Biomedical Engineering
Area Consultants: Clancy, Pedersen, Papageorgiou, Whitmal

Area Courses
BE 4011 Biomedical Signal Analysis
BE 4201 Biomedical Imaging

Related Courses
EE 2312 Discrete-Time Signal and System Analysis
BE 3011 Bioinstrumentation and Biosensors
BE 3110 Experimental Physiology for Engineers
BE 4101 Bioelectric Phenomena

Analog Microelectronics
Area Consultants: Bitar, Campbell, Labonte, McNeill, Papageorgiou

Area Courses
EE 2201 Microelectronics I
EE 3204 Microelectronics II
EE 3306 Audio Engineering
EE 3901 Semiconductor Devices
EE 4902 Analog Integrated Circuit Design

Related Courses
ES 3011 Control Engineering I
EE 3801 Advanced Logic Design
EE 3902 Introduction to VLSI Design

Computer Engineering
Area Consultants: Clancy, Cyganski, Duckworth, Hakim, King, Looft, Michalson, Pahlavan

Area Courses
EE 2801 Foundations of Embedded Computer Systems
EE 3801 Advanced Logic Design
EE 3803 Microprocessor System Design
EE 3815 Digital System Design with VHDL
EE 3902 Introduction to VLSI Design
EE 4801 Advanced Computer System Design

Related Courses
EE 2201 Microelectronics I
CS 2223 Algorithms
CS 3013 Operating Systems
CS 3733 Software Engineering

OFF-CAMPUS MQP OPPORTUNITIES

The ECE Department offers off-campus MQP opportunities in the following locations: Copenhagen, Denmark; Limerick, Ireland; Silicon Valley, California; and at the NASA Goddard Space Flight Center in Greenbelt, Maryland. These projects are performed as one-term, fulltime MQP experiences; some require a PQP or specific background preparation. Students can submit applications for these programs during B term of the academic year prior to their MQP (typically their junior year). For more information on these and other WPI off-campus programs, please visit the WPI Global Perspective Program website at http://www.wpi.edu/Academics/Depts/IGSD/Projects

ECE DESIGN COURSE

The most explicit educational background for the MQP is the course EE 2799, Electrical and Computer Engineering Design. In EE 2799, students spend the term working on a specific design project. The students not only gain experience in the design of a particular system, component, or process, but they also learn a great deal about the design process itself. Moreover, the course is a great opportunity to work on an exciting project with a team of students. (For more information please see the course description.)

Since EE 2799 is direct preparation for the MQP, students are strongly encouraged to successfully complete the course before seeking a senior project. Most ECE faculty will not accept MQP students until they have passed EE 2799.

Before you can pass EE 2799 though, you need to be adequately prepared. As is true for most ECE applications, the projects in EE 2799 require solid background in a variety of sub-disciplines, and thus it is necessary to learn these fundamentals before taking the course. As background for EE 2799, we strongly recommend (1) all four courses in the "basic core", and (2) at least one of the four courses in the "advanced core". These two sets of core courses are explained further in the next section.

Given these recommendations, the best time to take EE 2799 is at the end of your sophomore or beginning of your junior year, once this recommended background has been completed. For more on year-by-year planning, see the section titled "Planning a Program in ECE."

CORE COURSES

Although electrical and computer engineering is a vast and rapidly expanding field, there remains at its center a core of basic principles. These fundamental concepts, which have changed remarkably little throughout the rich history of electrical engineering, continue to serve as a basis for even the newest technologies. Accordingly, we consider developing a mastery of these fundamentals to be one of your most important tasks as an undergraduate student.

Core courses in the ECE department are divided into two groups: the "basic core" and the "advanced core". Together, these eight courses represent the bulk of ECE fundamentals, constituting much of what you will need to know as you prepare for EE 2799 and your MQP. The basic core is composed of four courses:

- EE 2011 – Intro to ECE
- EE 2022 – Intro to Digital Circuits and Computer Engineering
- EE 2111 – Physical Principles of ECE Applications
- EE 2311 – Continuous-Time Signal and System Analysis

These courses provide a comprehensive introduction to the fundamentals of ECE. Although you should consult the individual descriptions for each course to obtain detailed information about all the topics covered, the basic core amounts to an overview of central topics in ECE, including basic analog and digital circuits, introductory computer engineering, continuous signals and systems, electric power applications, and basic electromagnetic field theory. Before you attempt EE 2799, we strongly recommend that you take all four of these courses.

The advanced core is composed of another four courses, which are extensions of the material in the basic core:

- EE 2201 – Microelectronic Circuits I
- EE 2801 – Foundations of Embedded Computer Systems
- EE 2112 – Electromagnetic Fields
- EE 2312 – Discrete-Time Signal and System Analysis

Based on preference, you should take at least one of these courses before attempting EE 2799, so you can enter with a greater proficiency in at least one sub-area of ECE. Note, though, that the material in the advanced core is considered fundamental to study in our department, and every student, whether pursuing the ECE or the EE degree, eventually should take all of the courses in the advanced core.

OVERVIEW OF OTHER PROGRAM COMPONENTS

ENGINEERING SCIENCE AND DESIGN

Because modern engineering practice is increasingly interdisciplinary, all students achieve some breadth of study outside of the ECE department by taking a minimum of one Computer Science and one Engineering Science course. Both courses must be at the 2000-level or higher, and certain courses with limited technical content are not credited towards this requirement. (See the formal requirements listed previously in the distribution requirements.) In the Computer Science area, most students will need to complete a CS course at the 1000-level before attempting requirements at the 2000-level or above. Many students find it advantageous to take more than the minimum CS course requirement.

The Engineering Science courses represent cross-disciplinary areas that are applicable to many engineering and science departments. Alternatively, a survey course in Mechanical Engineering (ME 3601) can be taken in place of this Engineering Science requirement, and provides an excellent overview of those Mechanical Engineering topics of interest to ECE students.

MATHEMATICS AND SCIENCE

To succeed in the study of electrical and computer engineering, the necessary foundation far exceeds what can be taught in a few introductory courses. In fact, if you even want to begin to understand what your ECE professors are talking about in lecture, you must begin with a firm basis in mathematics and the natural sciences. Moreover, whether applied to ECE or not, proficiency in mathematics and the sciences is a necessary quality for *any* educated engineer. Consequently, both ECE and EE majors require 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, and differential equations. In addition, all ECE majors must take probability and/or statistics, though we recommend this material for EE majors, as well. To see which specific courses fulfill these math requirements, please consult the mathematics course descriptions, the *Planning a Program in ECE* section, 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 or EE 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.

For both majors, we require at least 3 courses in the sciences. For the newer ECE degree, 2 of these courses must be in physics, and the remaining course may be in chemistry or biology depending on preference. The older EE degree requires that the 3 courses be composed of either 2 physics courses and 1 chemistry course, or 1 physics course and 2 chemistry courses.

Finally, note that in both degree programs, 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").

PLANNING A PROGRAM IN ECE

The following section is intended to be a guide for planning your ECE or EE degree program. Of course, it is by no means a *complete* guide—you should consult several other important sections of this catalog for further information. These sections include WPI's general degree requirements, information regarding the three required projects (Sufficiency, IQP, MQP), and the specific descriptions for any courses we have mentioned. Also, be sure to consult your academic advisor in any matters related to the course scheduling and the fulfillment of degree requirements.

A NOTE ON ACADEMIC ADVISING

Our department—and WPI as a whole—offers you the opportunity of an education that is highly individualized. As no two students are identical in terms of their academic skills, interests, and aspirations, no two students should have identical academic programs. This chance to tailor a degree program to your individual needs is indeed a great opportunity, and the burden of seizing such an opportunity falls primarily on you, the student. However, adapting to WPI's complex system of courses, projects, and other degree requirements is certainly not an easy task.

Fortunately, you possess a great set of resources to help you, including your peers, the faculty and staff of the ECE department—and most importantly—your academic advisor. As you proceed through your years of undergraduate education, always remember that your academic advisor can be of great assistance. He or she is a source of advice and information, helping you with decisions about what courses to take, what projects to pursue, your personal and professional development, and how ultimately to make the most of your WPI experience. Your academic advisor can even help you find a job or get accepted to a graduate program.

As you get to know your academic advisor, remember: though he or she may contribute as much guidance as possible, most of the effort in planning your program must come from you. If, though, you simply cannot work well with your academic advisor for any reason, it is your responsibility to find one with whom you are more comfortable.

FRESHMAN YEAR

Planning your first year at WPI may appear confusing and difficult, especially since there are so many different options. This section will help you make sense of these options, and identify the courses that are most important to complete freshman year. Always remember, though, that there is no single "perfect" academic program.

As mentioned earlier, before you can begin coursework in the ECE Department, you need a proper foundation in mathematics. You should begin by completing differential and integral calculus as soon as possible. If you have insufficient background in pre-calculus topics, you may begin with the semester-long MA 1020 course. If not, then you should begin with MA 1021. In either case, you should definitely follow with MA 1022. Students with a background in high school calculus (such as an AP course) may skip ahead to begin with MA 1022, MA 1023, or even MA 1024. Consult your advisor to find out which starting point is right for you. Incidentally, note that MA 1020/1021 and MA 1022 fulfill the differential and integral calculus part of the "Mathematics and Basic Science" distribution requirement (for both the ECE and EE majors).

The next step in planning your freshman year is to address the science requirement, especially with one or two physics courses. The physics courses most directly relevant to ECE are PH 1120 or PH 1121 (which deal with electricity and magnetism) and PH 1140 (which deals with oscillations and waves). When choosing physics classes, be sure to pay attention to any recommended background such as calculus. You may also consider taking a chemistry or biology course in your freshman year. We encourage students to investigate further any mathematics or science courses that they find interesting; as always, consult your academic advisor for help.

For many students—in particular those with little experience in programming—freshman year is the best time to address the computer science requirements of the ECE and EE degrees. For students with a moderate background in computers, either CS 1005 or CS 1006 provides a suitable introduction to programming concepts. You may then continue on to more advanced computer science courses such as CS 2005.

If you have planned properly, you should be ready to begin coursework in ECE or EE by the spring semester of your freshman year. The first course for all students should be EE 2011, usually followed by EE 2022. A majority of ECE and EE students begin their major coursework with EE 2011 in C-term of their freshman year, followed by EE 2022 in D-term. If you feel that you are not ready to take EE 2011 by C-term, the course is offered again in D-term, and you can even wait until A-term of your sophomore year. Whenever you begin with your major coursework, be sure to complete the recommended background for EE 2799 in time to take it in your sophomore or junior year.

In addition to all of your major coursework and its related background, do not forget that, at some point, you will need to complete a Sufficiency project! You may want to schedule some Sufficiency-related coursework for your freshman year, especially if you want to complete the project in your sophomore year. Also, as social science courses, such as economics, are typically helpful for the IQP, you may want to take those courses as soon as possible (or at least at some point before your junior year). Finally, do not forget the physical education requirement.

In choosing your courses for freshman year, keep in mind that the WPI degree requirements call for three "free elective" courses; if you pass all of your classes at WPI, you will end up with a total of six courses which you can choose with no restrictions whatsoever. This flexibility can be used for a variety of purposes, such as pursuing another major or minor, delving deeper into your Sufficiency area, honing your skills within your major beyond the minimum courses required, or even just taking a few extra courses that interest you. In other words, do not be afraid early on to take a course simply because it may not be "worth credit" toward your degree. Freshman year is a great time to explore the wide array of topics a WPI education has to offer.

SOPHOMORE YEAR

As you plan for your sophomore year, one important task will be to continue progress in your major. This process is assisted by careful planning on your part, particularly if want to take EE 2799 by D-term of your second year.

The following tables display two examples of desirable course sequences for an ECE or EE student. Both show series of courses that would allow a student to arrive at EE 2799 in D-term with the proper recommended background (without considering such factors as recommended mathematics or science).

Example #1:

Term		Course
Freshman	C	EE 2011
	D	EE 2022
	A	EE 2111
Sophomore	B	EE 2311
	C	Any course in the advanced core
	D	EE 2799

Example #2:

Term		Course
Freshman	C	EE 2011
	D	EE 2022
Sophomore	A	EE 2801 or EE 2201
	B	EE 2311
	C	EE 2111
	D	EE 2799

Of course, if you desire even greater flexibility in your schedule, there are many paths besides these two. For example, you may take two ECE courses concurrently in a term, provided that one is not recommended background for the other. Also, you may wait until B-term of your junior year to take EE 2799; this decision may be helpful if you chose not to start your ECE classes until later, or if you want to have a stronger background in ECE, mathematics, or science before attempting the course. However, we do advise against waiting until the *end* of junior year (or later) to take EE 2799, as it may hinder your ability to find an MQP on time.

By the end of sophomore year, you should have finished taking most of your mathematics and science classes, as these courses serve as background for further work in your major. Also, all ECE and EE students should complete the computer science requirement in this year, if they have not yet done so.

Many students choose to complete their Sufficiency project in the sophomore year. If you have finished the 5 courses requirement for the Sufficiency, then you may consider this option. Before you schedule your project, be sure to find and approach an advisor with whom you would like to work. On the other hand, if you did not make much progress in completing humanities courses as a freshman, you should do so in this year. Do not feel rushed, though—you do not necessarily have to complete your Sufficiency requirement as a sophomore. Some of the best Sufficiency projects at WPI are completed by juniors and seniors, so feel free to schedule your work in the humanities in a way that best suits you.

Another important task in your second year is to investigate WPI's "Global Perspective Program". Many WPI students perform their IQP at an off-campus project site; this is especially true in the ECE Department. However, if you are planning to complete your IQP off-campus as a junior, the application process begins in your *sophomore* year. For more information about off-campus projects, see the "Projects" section of this catalog, or contact the Interdisciplinary and Global Studies Division (IGSD).

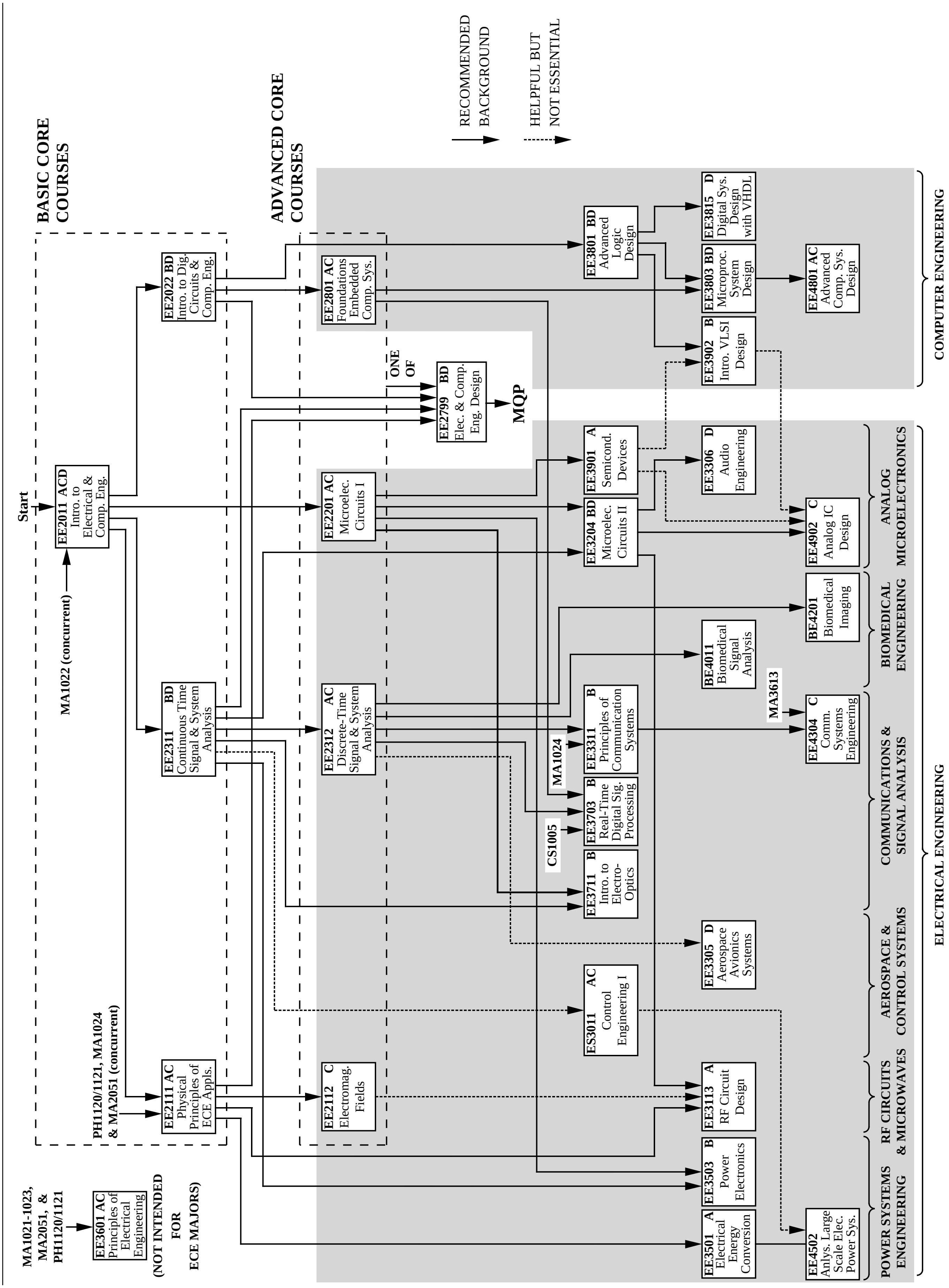
Finally, keep in mind that by the end of sophomore year, you should be sufficiently educated in ECE to attempt an internship in industry during the following summer, if you so desire. If you are interested, be sure to talk to your academic advisor, and investigate the resources available at WPI's Career Development Center.

JUNIOR YEAR

With all the freshman- and sophomore-level background finally completed, your third year of education in the ECE department offers you a chance for greater flexibility and control over you degree program. However, if you have yet to do so, your first priority is to complete EE 2799. Also, once the design course is completed, you should finish the remaining courses in the advanced core as soon as possible.

After that, you will finally have a chance to branch out into the many other ECE courses we offer. When choosing major courses for the junior year, be sure to seek a balance between depth and breadth. On one hand, there is a wide selection of 3000-level courses from which to choose, extending the basic and advance core into even more areas of ECE. These courses will allow you explore more of the discipline, and gain even greater proficiency in any of the core areas you may have found interesting. On the other hand, if you are particularly interested in a single sub-discipline, you may be ready by the end of junior year to attempt a 4000-level course (depending of course on the specific class and its recommended background).

ELECTRICAL AND COMPUTER ENGINEERING COURSE FLOW CHART



Despite the opportunities available to you in ECE, the most substantial component of your work junior year will most certainly be your Interactive Qualifying Project. If you are planning to complete your IQP off-campus, be sure to take additional care in planning your courses around the term that you will be away. Also, in the term before you leave, off-campus projects typically require 1/3 unit or more of preparatory work. You should take this extra burden into account as part of the workload for that term.

Yet another key undertaking of the junior year is your responsibility to find an MQP. If you are planning to do the project off-campus as a senior, you will need to follow an application procedure similar to that of off-campus IQPs. If you are planning to complete the project on-campus, then the efforts needed to find a project may vary greatly. You may need to apply to and interview for certain industry-sponsored MQP programs, or you might contact a professor in the department who has advertised a specific project he or she wants to advise. Consult with your academic advisor about what types of projects interest you, and what approach is best to secure an MQP for the next year.

Finally, do not forget about your Sufficiency, your social science courses, the ES requirement, and your physical education classes.

SENIOR YEAR

Depending on how well you have done in developing your degree program in the previous three years, planning for senior year can be a breeze—or a disaster. However, even if you are new to the idea of taking academic planning seriously, there is still plenty you can do to ensure that you will be walking across the stage on graduation day.

By far, the most important part of your senior year is your MQP. The ways of scheduling your project are quite varied, depending on the type of project, location, students, and advisors. Off-campus MQPs last for about 1 term, and are offered A-term, B-term, and C-term at various locations (see “Off Campus MQP Opportunities” in the “Overview of ECE Program Components” section). A typical on-campus MQP usually requires 1/3 unit of work in three consecutive terms—commonly A-term through C-term of the senior year. From time to time senior projects may run longer, extending into D-term. Any student wishing to graduate on time, however, must remember two things: (1) all MQP students must be ready to give their final presentations on the annual Project Presentation Day in April, and (2) the final MQP report, with the proper accompanying paperwork, must be submitted by the registrar’s specified deadline.

If your MQP is on the right track, the next step is to choose your remaining ECE courses, which can be accomplished in many different ways. Some students select courses that will directly help them in an upcoming job or graduate program. Other students choose courses to supplement the topics they are covering in their MQP. Some use the remaining courses to expand their breadth of knowledge into an area where they are weak, while others use senior year to take those one or two 4000-level courses in areas where they desire more expertise. All of these approaches are valid; the important thing is to think critically about your academic goals, and choose a path that best fits your current academic program, while allowing you to explore courses that appear interesting.

Besides your remaining major coursework, your plan for senior year must include everything else you need to complete to graduate. For example, some students choose to do their Sufficiency project senior year. Also, do not forget the many other degree requirements that we have repeatedly mentioned—you certainly do not want to graduate late because you forgot 1/12-unit physical education class! Be sure to have your academic advisor check your course plan at the beginning of senior year, to verify that you have not overlooked anything.

GRADUATION AND BEYOND

There is one essential task of any senior year student that we failed to mention in the previous section. As the year progresses, seniors have to plan for the “next step”—their lives *after* graduation.

A common direction for students to choose upon graduation is full-time employment. The job-seeking process is not always easy, requiring mastery of many important life skills, such as writing a resume or participating in a job interview. Fortunately, there are many resources available to aid you in this process, including the Career Development Center, your academic advisor, other professors, and your peers. One of the best places to network with potential employers is at any of the regularly scheduled “career fairs”, when companies send representatives to WPI to search for qualified applicants. Also, do not forget to utilize the internet as a tool for publishing resumes and investigating potential employers. Since a thorough and comprehensive job search can last several months, be sure to start early.

Another option is to continue with a program of academic study—typically a graduate degree. If you wish to begin study in the fall semester, realize that most graduate schools set their application deadlines in December or January, and the deadlines for many fellowship competitions may occur even earlier. In any case, if you are interested in beginning a graduate program directly after graduation, you should be investigating potential schools, the programs they offer, and any fellowships or scholarships that may be available by the end of your junior year and during the following summer. Once again, the Internet can provide invaluable assistance during this effort. Note that many graduate school and fellowship applications require you to take certain standardized tests, such as the Graduate Record Examinations (GRE’s). Be sure to investigate thoroughly dates of preparation courses, test dates, and the delay time for receiving test results. You must allow time to prepare for and take all the necessary tests, and still receive the results in time to use with your graduate applications. Finally, do not forget that a degree in ECE or EE is useful for far more than a future in engineering. The degrees we offer are excellent preparation for a wide array of graduate studies, including education, business, or law.

When choosing one of these routes, keep in mind that here in the ECE department, we expect from you a commitment to lifelong learning. In other words, even if you choose not to continue immediately with your formal studies, it does not mean the end of your education! First of all, there is always the chance to learn within a job in industry, through projects, training programs, and other learning opportunities. Furthermore, many students decide to return to graduate school after a few years of working, often finding that such "real-world" experience is a great advantage upon returning to academia. Regardless of the path you choose after leaving the ECE department, always remember that your WPI degree (while extremely valuable) is certainly not the end of your education—it is only a foundation for years of learning yet to come.

STUDENT GROUPS IN ECE

A good way to ensure a commitment to lifelong learning is through membership in engineering-related organizations such as professional societies. Professional societies are a vital aid to the dissemination of technical knowledge, helping engineers in industry remain abreast of recent discoveries. Accordingly, we encourage you to include membership in these kinds of organizations as part of your cocurricular activities.

With more than 350,000 members, the Institute of Electrical and Electronics Engineers (IEEE) is the world's largest technical professional society. The IEEE supports a number of student chapters, which are responsible for more than 50,000 of its active members. The IEEE student chapter at WPI is particularly active: in addition to managing the undergraduate lounge on the first floor of Atwater-Kent Laboratories, student members host department-wide events such as information sessions, guest speakers, and barbeques. Another student group is WECE (Women in Electrical and Computer Engineering), which offers women students a chance to meet and discuss academics, employment, and other opportunities in ECE.

Students in the ECE department are also eligible for nomination to various honor societies. Eta Kappa Nu (HKN) is the international honor society for students in electrical and computer engineering. In addition to honoring outstanding students in the department, HKN organizes a number of activities, awards, and scholarships. Exceptional students in the ECE department are also eligible to become elected members of Tau Beta Pi (TBP), the international honor society for all engineering students. For both societies, students exhibiting the necessary qualities of scholarship, leadership, and character are approached for membership in either their junior or senior year of study.

TRANSFER STUDENTS

Since the ECE department's introductory curriculum is different from the traditional program offered at many other schools, transfer students must be sure to confer with their advisor to plan their WPI program. Transfer students with no previous ECE courses should begin the program in the same way as first-year students. Students with some transfer credit may be able to omit one or more of the introductory courses. Those with one or more courses in circuit theory and substantial laboratory experience should consider omitting EE 2011, and possibly one or more of the other basic core courses, but this should only be done after consultation with an academic advisor.

INFORMATION FOR NON-MAJORS

Students who wish to develop a background in electrical and computer engineering are advised to consult with a faculty member in the ECE Department. A basic foundation in electric circuits and electronics may be obtained by taking EE 2011, EE 2111, EE 2201, and EE 2311. A basic foundation in the elements of computer engineering may be obtained by taking EE 2011, EE 2022, EE 2801, and EE 3801. An overview of basic electric circuits can be obtained by taking EE 3601.

Electrical and computer engineering may be coupled with other areas of study to define a unique interdisciplinary program. Students contemplating such an innovative program should contact the Interdisciplinary and Global Studies Division for guidance and approval, especially with regard to the selection of a suitable MQP and arrangements for program-specific distribution requirements; see *Interdisciplinary Programs* for more information.

MINOR IN COMPUTER ENGINEERING

This interdisciplinary minor requires students to develop competence in areas of computer engineering, including both hardware and software aspects of computer systems. This minor is not available to students majoring in EE or ECE. Students majoring in EE may file for a Concentration in Computer Engineering with Prof. Looft.

Selected rules for a Minor include the following:

1. Two or more units of thematically related activity.
2. Concluding 1/3 unit of the Minor must be a capstone experience.
3. A Minor may include any portion of the academic program, excluding the MQP.
4. At least one-unit of the Minor, including the capstone activity, must be free electives.
5. The Program Review Committee for a Minor area will consist of faculty members designated by the sponsoring faculty members.

In order to be eligible to receive the Computer Engineering Minor designation, at least six computer engineering related ECE and CS courses must be included in the distribution requirements, listed below. Other appropriate courses may be substituted with the approval of the Computer Engineering Minor Program Review Committee.

A. At least three of the following ECE courses must be included.
- EE 2801 Foundations of Embedded Computer Systems
- EE 3801 Advanced Logic Design
- EE 3803 Microprocessor System Design
- EE 3815 Digital System Design with VHDL
- EE 3902 Introduction to VLSI Design
- EE 4801 Advanced Computer System Design
- EE 505 Computer Architecture

B. At least three of the following CS courses must be included.
- CS 2011 Introduction to Machine Organization and Assembly Language
- CS 3013 Operating Systems
- CS 3733 Software Engineering

- CS 4513 Distributed Computer Systems
- CS 4514 Computer Networks
- CS 4515 Computer Architecture (can not be counted if EE 505 is selected)

C. Capstone Courses
The following courses may be used to satisfy the Computer Engineering minor capstone requirement: EE 3803, EE 3815, EE 3902, EE 4801, CS 4513, CS 4514, CS 4515.

ENGINEERING SCIENCE COURSES

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

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

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

ENGINEERING PHYSICS

ADVISOR: T. H. KEIL

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

ENVIRONMENTAL PROGRAMS

Undergraduate students may pursue environmental studies at WPI through a variety of programs and departments.

Students should review these programs as listed below, and talk with their academic advisors and the respective program coordinators, to help make a good choice of environmental major at WPI. In every program, the WPI project requirements, both in the major field and the IQP, will provide unusually strong support for defining specific career directions. Students are also urged to make use of the "Global Perspective Program" to carry out one project abroad, and thus attain a sense of environmental studies at a global, cross-cultural level.

ENVIRONMENTAL ENGINEERING

Civil/Environmental Engineering with Emphasis on Water Quality Control

Coordinators: Profs. O'Shaughnessy, Hart, Mathisen, Plummer, or Bergendahl, Civil Engineering

The Department of Civil Engineering at WPI provides courses leading to an ABET-accredited degree in Civil Engineering. Areas of concentration include the planning, design, construction, operation and regulation of water quality control systems related to water supply and waste treatment. Related issues include public health and solid waste management. The engineering focus is in the area of large systems associated with municipal and other public projects.

Students majoring in this program would follow a general curriculum in Civil Engineering, with emphasis on the environmental engineering subarea. Such preparation leads to a degree recognized by the professional accrediting organization, ABET (Accreditation Board for Engineering and Technology), and is an excellent start for entry-level professional placement or graduate study in environmental engineering.

Chemical/Environmental Engineering with Emphasis on Pollution Prevention and Abatement Technology

Coordinators: Profs. Wyslouzil, Thompson, Ma, Dixon, DiBiasio, or Clark, Chemical Engineering

The Department of Chemical Engineering at WPI provides a general curriculum leading to an ABET-accredited degree in chemical engineering. Undergraduates can become involved in a specialty area of environmental engineering through their MQP or other independent projects, and are encouraged to work with faculty in their own areas of research in these fields. Today's chemical engineers are challenged to help maintain industrial competitiveness while ensuring a healthy environment. Chemical engineers with environmental emphasis design and develop environmentally benign chemical processes aimed at preventing pollution at its source by recycling or eliminating all hazardous components. Additionally, they are involved in developing environmentally friendly products like biodegradable packaging materials. Chemical engineers' understanding of the physical and chemical properties of pollutants makes them uniquely qualified to develop technical solutions to current environmental problems of soil, water, and air pollution.

Students majoring in this program would follow a general curriculum in Chemical Engineering, with elective coursework in environmental engineering and environmental related project work. Such preparation leads to a degree recognized by the professional accrediting organization, ABET (Accreditation Board for Engineering Technology), and is an excellent start for entry-level professional placement or graduate study in environmental engineering.

Manufacturing/Environmental Engineering with Emphasis on Environmentally-Conscious Manufacturing

Coordinator: Prof. Sisson, Manufacturing Engineering

The Manufacturing Engineering program at WPI provides a general curriculum leading to an ABET-accredited degree in manufacturing engineering. Undergraduates can become involved in a specialty area of environmental engineering through their MQP or other independent projects, and are encouraged to work with faculty in their own areas of research in these fields. One of the fastest growing research areas within manufacturing engineering is that of design for the environment and environmentally-conscious manufacturing. Since manufacturing engineering is multi-disciplinary by nature, students can join the program with interests in environmental engineering, computer science, management, and electrical or mechanical engineering, or with other interests.

Students majoring in this program would follow a general curriculum in Manufacturing Engineering, with emphasis on environmental engineering course and project work. Such preparation leads to a degree recognized by the professional accrediting organization, ABET (Accreditation Board for Engineering and Technology), and is an excellent start for entry-level professional placement or graduate study in environmental engineering, manufacturing engineering, or management.

ENVIRONMENTAL SCIENCES

Biology-Biotechnology/Environmental Sciences

Coordinator: Prof. T. Crusberg, Biology & Biotechnology

The department of Biology & Biotechnology offers a curriculum leading to a degree in Biology & Biotechnology with a concentration in Ecology and Environmental Biology. Relevant topics under investigation by the departmental faculty include bioremediation, behavioral and conservation ecology, release of genetically altered organisms, and micro environmental regulation of growth and development in bioreactors. Course work in marine ecology is also available off campus through a cooperative arrangement with the Marine Biological Laboratory in Woods Hole. Off campus project work in conservation ecology with the Mass. Audubon Society and the Mass. Div. of Fisheries and Wildlife occurs as demand warrants.

Students with Biology & Biotechnology degrees will be prepared for entry-level professional work, or for graduate studies leading to a master's or doctoral degree.

ENVIRONMENTAL ECONOMICS AND PUBLIC POLICY

Social Sciences and Policy Studies

Coordinators: Profs. Saeed or Rissmiller, Social Sciences and Policy Studies

The Department of Social Sciences and Policy Studies at WPI provides a general curriculum leading to degrees in three separate areas: Economics and Technology, Society-Technology, or Economics. Students interested in careers in environmental studies involving any of these three areas could pursue programs in SSPS, leading to careers in business, research, or government.

Students majoring in one of these three SSPS programs will be prepared for entry-level professional work, or for graduate study either for the MBA or a master's or doctoral research program.

ENVIRONMENTAL STUDIES

Humanities/Environmental Studies

Coordinator: Prof. R. Gottlieb, Humanities & Arts Department

The Humanities Department at WPI offers a general curriculum leading to degrees with concentrations in literature, philosophy and religion, and history. Students interested in humanistically-oriented environmental studies could major in the humanities, and take a specifically designed program involving one or more of these areas. Career possibilities upon graduation would include law, business, government service, environmental activism, journalism, or graduate study in the humanities.

Interdisciplinary Environmental Studies

Coordinator: Prof. Davis, Interdisciplinary and Global Studies Division

Students wishing to design their own unique program in any field of environmental studies at WPI can do so through the Interdisciplinary and Global Studies Division (IGSD). Such a program might, for example, involve roughly equal areas of study in biology and biotechnology, chemical engineering, and social science and policy studies. Many other possible combinations also exist, with differing levels of study in both scientific and technological disciplines, and in social sciences, policy studies or humanities (ethics). Examples of areas for major study include (but are not limited to):

- identification and production of micro-organisms to remove heavy metals from the water supply, and
- technical writing for environmental organizations.

Interdisciplinary programs are coordinated through the IGSD, and advised by a panel of three faculty from different disciplines. Many students also explore the course offerings at Clark University and the College of the Holy Cross, which are available at no cost through the Worcester Consortium. Students with interdisciplinary programs will be prepared for entry-level professional employment or graduate study.

FIRE PROTECTION ENGINEERING

D. A. LUCHT, DIRECTOR;
PROFESSORS: J. R. Barnett, R. W. Fitzgerald, D. A. Lucht, R. E. Zalosh
ASSOCIATE PROFESSORS: , N.A. Dembsey, F. Noonan, B. J. Savilonis
ASSISTANT PROFESSOR: J. P. Woycheese
AFFILIATE PROFESSORS: W. K. Kim, P. J. Pagni, E. S. Yoon

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.

EDUCATIONAL GOALS

- 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.

INTRODUCTION

Fire protection engineering is one of the best kept secrets in career education today. Employers and personnel recruiters consistently report good job opportunities each year. Starting salaries have proved to be competitive and generally above the overall engineering profession average.

Fire protection engineers can be called upon to provide a broad range of services. Some perform firesafety evaluations of buildings and industrial complexes to determine the risk of fire losses and how best to prevent them. Others design systems which automatically detect and suppress fires and explosions as well as fire alarm, smoke control, emergency lighting, communication, and exit systems. Fire protection engineers perform research on materials and consumer products or the computer modeling of fire and smoke behavior. Others investigate fires or explosions, preparing technical reports, or providing expert courtroom testimony in civil litigation cases.

Fire protection engineers work at the nerve centers of large corporations and oversee the design and operational firesafety of complex manufacturing facilities in multinational business networks. They also work for insurance companies, surveying major facilities, and performing research, testing, and analysis.

Fire protection engineers can be found at all levels of government, worldwide. They work for architectural and engineering firms and specialty consulting groups. Interesting jobs are available in trade associations, testing laboratories, and at colleges and universities.

WPI's one-of-a-kind fire protection engineering program offers a variety of educational opportunities to suit most every student need. These include the combined degree program through which the student may earn an undergraduate degree in one of the traditional disciplines and the master's degree in fire protection engineering in as little as five years. The master of science, and doctor of philosophy in fire protection engineering are also available.

For those interested in preparing for a career in this challenging field, we recommend obtaining a B.S. degree in one of the traditional engineering disciplines and developing the experience in solving fire-related problems through qualifying project work under the supervision of faculty from WPI's Center for Firesafety Studies. An introductory undergraduate course (FP 3070 Fundamentals of Firesafety Analysis) makes an excellent companion to the qualifying project.

For advisory information (including a free fire protection engineering careers video or CD-Rom), students may contact Prof. D. Lucht, Director of the Center for Firesafety Studies.

COMBINED-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 B.S. 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's degree. Holders of B.S. degrees in traditional engineering or science disciplines and the master's degree in fire protection engineering enjoy extremely good versatility in the job market.

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 and the master's degree in fire protection engineering in five years.

GRADUATE INTERNSHIPS

A unique graduate internship program is available, allowing students to gain important clinical experiences in practical fire protection engineering and research environments. Students are able to earn income, alternating work and on-campus classroom and laboratory activities.

HUMANITIES AND ARTS

P. J. M. QUINN, HEAD
PROFESSORS: F. Bianchi, J. J. Brattin, S. C. Bullock, D. B. Dollenmayer, R. S. Gottlieb, K. P. Ljungquist, J. Manfra, L. J. Menides, W. T. Mott, P. J. M. Quinn, A. A. Rivera, L. E. Schachterle, T. A. Shannon, M. M. Sokal, J. Trimbur, S. Vick, J. F. Zeugner
ASSOCIATE PROFESSORS: W. A. B. Addison, Jr., L. J. Curran, J. P. Hanlan, P. H. Hansen, E. M. Parkinson, M. D. Samson, R. L. Smith
ASSISTANT PROFESSORS: M. K. Ephraim, H. J. Manzari, J. Sanbonmatsu
ADJUNCT FACULTY: J. Arend, W. A. Baller, T. W. Code, M. C. Davila, J. Delorey, R. G. Falco, J. L. Forgeng, M. C. Gherardi, D. E. Gray, P. M. Lahey, G. K. Lew, M. Manzari, B. L. McCarthy, C. Merithew, T. Naksa, D. O'Donnell, M. E. Pignataro, J. R. Policelli, S. Runstrom, J. E. Watters, D. G. Weeks
PROFESSORS EMERITUS: D. McKay, E. Hayes, C. Heventhal

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

INTRODUCTION
The humanities and arts–art history and architecture, drama/theatre, foreign languages, history, literature, music, philosophy, religion, and writing/rhetoric–are central to WPI's vision of the new "liberal education." All WPI undergraduates devote a significant portion of their academic program to the humanities and arts either through a "Humanities and Arts Sufficiency Program" or through a major, double-major, or minor in the department.

The humanities and arts promote intellectual curiosity and maturity by developing the essential skills for further study and lifelong learning. These include the ability to think critically, to write and speak clearly and persuasively, to appreciate and cultivate the literary and aesthetic arts, and to understand the rich cultural diversity of the world in the past and present. Students in the humanities and arts grapple with fundamental questions of justice, value or meaning through reading, observation, creation, interpretation, and performance. These are, in fact, the activities of the highly productive Humanities and Arts faculty, which is well regarded for research, publication and creative work. Through the humanities and arts, the faculty enable students to gain self-knowledge and to broaden cultural horizons.

The Department of Humanities and Arts offers a variety of opportunities for students to pursue personal interests. The Department offers an interdisciplinary curriculum, in which students may investigate multifaceted topics using a variety of approaches. The major or double-major in Humanities and Arts is interdisciplinary in scope (see page 117). In addition, the Humanities and Arts Sufficiency Program may culminate in a thematic project that integrates previous courses from several areas of the humanities and arts. The Sufficiency Program also might result in a theatrical or musical performance or in proficiency in a foreign language. Students should also consider unique opportunities to complete a Sufficiency Project at a Global Project Center. (For details of the Sufficiency Program, see page 54.)

The close working relationship among students and faculty in the humanities and arts at WPI promotes academic excellence, innovative thinking, and mutual respect. In short, the Humanities and Arts Department is committed to helping students develop both a knowledge of, and the ability to think critically about, the humanities and arts. We also seek to foster the skills and habits of inquiry necessary for such learning-analytical thought, clear communication, and creative expression. Such an education provides a crucial foundation for responsible and effective participation in a complex world.

HUMANITIES AND ARTS MAJOR
The Humanities and Arts major requires six units of work, including the MQP. Students take courses from across the humanities and arts, but may choose to focus their program of study by completing a Concentration as described below.

The major or double-major in Humanities and Arts is excellent preparation for a variety of careers. Humanities and Arts graduates from WPI 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, literary and musical composition or performance.

In addition, since each Humanities and Arts major completes either a "technical sufficiency" 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.

Program Distribution Requirements for the Humanities and Arts Major

1. Humanities and Arts (including MQP) (Note 1)	6
2. Electives (Note 2)	4

NOTES:

1. Humanities and Arts majors may choose to complete 2 units of work and an MQP in one of the following areas of Concentration: History, Literature, Music, Philosophy, Religion, Drama/Theatre, Writing and Rhetoric, Art History, German Studies, Hispanic Studies, American Studies, Environmental Studies, or Humanities Studies of Science and Technology.
2. May be from any area except Aerospace Studies, Military Science, or Physical Education. Courses used to satisfy other degree requirements (i.e. the IQP and the Sufficiency) may not be used to fulfill this requirement.

CONCENTRATIONS FOR HUMANITIES AND ARTS MAJORS

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

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

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

REQUIREMENTS

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

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

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

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

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

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

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

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

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

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

HUMANITIES AND ARTS WITH AMERICAN STUDIES CONCENTRATION

This interdisciplinary concentration examines American culture from the multiple perspectives of American history, literature, and politics. American Studies at WPI takes advantage of the unparalleled resources at the American Antiquarian Society.

1. 1/3 units: one of the following courses: HU 1411 Introduction to American Studies, EN 1231 Introduction to American Literature, EN 1257 Introduction to African American Literature and Culture, HI 1311 Introduction to American Urban History, HI 1312 Introduction to American Social History, or HI 1314 Introduction to Early American History.

2. 2/3 units from List 1 ("American History")
3. 2/3 units from List 2 ("American Literature")
4. 1/3 units from List 3 ("American Politics, Law, and Policy"). This may not include courses taken to fulfill the Social Science Requirement.
5. MQP in American Studies

List 1. American History:
- HI 2311 American Colonial History
- HI 2313 American History, 1789-1877
- HI 2314 American History, 1877-1920
- HI 2315 The Shaping of Post-1920 America
- HI 2316 American Foreign Policy from Woodrow Wilson to the Present
- HI 2317 Law and Society in America, 1865-1910
- HI 2331 American Science and Technology to 1859
- HI 2332 American Science and Technology from 1859
- 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:
- SS 1301 U.S. Government
- SS 1303 American Public Policy
- SS 1310 Law, Courts, and Politics
- SS 2121 Government Budgets and Fiscal Policy
- SS 1203 Social Problems and Policy Issues
- SS 2302 Science-Technology Policy
- SS 2304 Governmental Decision Making and Administrative Law
- SS 2310 Constitutional Law
- SS 2311 Legal Regulation of the Environment
- SS 3278 Technology Assessment and Impact Analysis Seminar

HUMANITIES AND ARTS WITH ENVIRONMENTAL STUDIES CONCENTRATION

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

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

List 1. Designated Environmental Courses in Humanities:
- AR 2113 Topics in 19th- and 20th-Century Architecture
- EN 2237 American Literature and the Environment
- HI 1311 Introduction to American Urban History
- HI 1341 Introduction to Global History
- HI 2334 European Technological Development
- HI 3331 Topics in Science, Technology, and Society
- HI 3333 American Technological Development
- PY 2712 Social and Political Philosophy
- PY 2713 Bioethics
- PY 2717 Philosophy and the Environment

List 2. Related Environmental Courses in Social Sciences.
- SS 2117 Environmental Economics
- SS 2125 Development Economics
- SS 2311 Legal Regulation of the Environment
- SS 2312 International Environmental Policy
- SS 2405 The Psychological Study of Environmental Issues
- SS 3278 Technological Assessment and Impact Analysis Seminar

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

HUMANITIES AND ARTS WITH HUMANITIES STUDIES OF SCIENCE AND TECHNOLOGY CONCENTRATION

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

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

List 1: Designated HSST Courses
- AR 2113 Topics in 19th- and 20th-Century Architecture
- EN 2252 Science and Scientists in Modern Literature
- EN 3215 Genres of Science Writing

HI 1331 Introduction to the History of Science
HI 1332 Introduction to the History of Technology
HI 2331 American Science and Technology to 1859
HI 2332 American Science and Technology from 1859
HI 2333 History of Science from 1700
HI 2334 European Technological Development
HI 3331 Topics in Science, Technology, and Society
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.

ID 3150 Light, Vision and Understanding and the Scientific Community
SS 2208 The Science-Technology Debate
SS 2302 Science-Technology Policy
SS 2304 Governmental Decision Making and Administrative Law
SS 2311 Legal Regulation of the Environment
SS 2312 International Environmental Policy
SS 3278 Technology Assessment and Impact Seminar

DOUBLE MAJOR IN HUMANITIES AND ARTS

Students may pursue a double major in Humanities and Arts and in an area of science, engineering, or management. To pursue the double major, a student must satisfy all of the degree requirements of the technical discipline including an MQP and Distribution Requirements. In addition, the double major in Humanities and Arts requires 6 units of studies in the Humanities and Arts, including the MQP. Students pursuing a double major, one of which is Humanities and Arts, are not required to complete a Sufficiency Program in Humanities and Arts, nor are they required to complete a second IQP. Students interested in pursuing this option should contact Prof. B. Addison, 39 Dean St., Room 260, for additional information.

The demand for graduates equipped with the background possessed by a WPI student with a double major in the Humanities and Arts is likely to increase. Many fields, including medicine, law, industry, theatre technology, commerce, and public service, will be open to those who have acquired both the skills of humanistic education and technical or managerial knowledge.

OTHER HUMANITIES AND ARTS MINORS

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

MINOR IN FOREIGN LANGUAGE (GERMAN OR SPANISH)

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

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

(This unit may be double-counted toward the Sufficiency. 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, 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 and Prof. Fontanella (for Spanish).

MINOR IN MUSIC

The minor in Music is for students who choose to continue their studies in Music beyond the Sufficiency project 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: F. Bianchi, L. Curran, or D. Weeks, in the Department of Humanities and Arts. Because performance is an integral component of music study with proposed minor will contain performance emphasis and consist of two units of work distributed as follows:

1. 1/3 unit for participation in MU IS/P Ensembles.
2. 1/3 unit Performance IS/P as the capstone experience. Student, with faculty guidance, will present a recital, original composition, or other musical performance that demonstrates the student's skill and knowledge.
3. 1 1/3 units of music courses.
4. If a student completes his/her Sufficiency project 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.

MINOR IN WRITING AND RHETORIC

The minor in Writing and Rhetoric offers students the opportunity to extend their study of writing and rhetoric beyond the Sufficiency requirement without majoring in either the Writing and Rhetoric concentration in Humanities and Arts or the Technical, Scientific, and Professional Communication program. The minor consists of two units of work, distributed in the following way:

1. 2/3 unit. Core courses in writing and rhetoric: RH 3111, RH 3112
2. 1 unit. Electives in writing and rhetoric, chosen from the following: EN/WR 2211, EN/WR 3214, EN/WR 3216, EN/WR 3217, EN/WR 3011, and RH 3211. If there is good reason and with the approval of the Program Review Committee, electives may also include courses in art history, literature (in English or other languages), and philosophy and religion.
3. 1/3 unit. Capstone IS/P.

No more than 1 unit of coursework may be double-counted toward the Sufficiency requirement.

INDUSTRIAL ENGINEERING

The Industrial Engineering major is a program of the Management Department. Please refer to page 123 for more information.

INTERDISCIPLINARY PROGRAMS

P. DAVIS, DEAN;
R. F. VAZ, ASSOCIATE DEAN;
N. MELLO, DIRECTOR OF GLOBAL OPERATIONS
S. VERNON-GERSTENFELD, DIRECTOR OF ACADEMIC OPERATIONS
ADJUNCT ASSISTANT PROFESSORS: F. Carrera, R. Krueger, C. Peet, G. Theyel

The Provost Office, in conjunction with the Interdisciplinary and Global Studies Division (IGSD), operates those academic functions or programs which require an interdisciplinary administrative structure. In addition, the IGSD also provides the support structure for students who construct individually-designed (ID) majors which cannot readily be accommodated in traditional academic departments.

ID majors may be defined in any area of study where WPI's academic strengths can support a program of study, *and* in which career goals exist. Many combinations of technical and non-technical study are possible. Do not be limited by the example given here; if you have questions about what programs at WPI are possible, please see Prof. R. Vaz in the Project Center to discuss how WPI can assist you in reaching your goals.

Procedure For Establishing an Interdisciplinary (Individually-Designed) Major Program

Students who wish to pursue an individually-designed major program should first discuss their ideas with their academic advisor. The student should then consult with the dean of the IGSD, Prof. Paul Davis, 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 Projects and 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.

EXAMPLES OF INTERDISCIPLINARY PROGRAMS

In recent years, students have graduated in interdisciplinary programs in the following areas:

Environmental (Water Pollution) - Civil Engineering
Environmental (Air Pollution) - Chemical Engineering
Urban and Environmental Planning - Civil Engineering

Courses for these programs are located *primarily in the departments listed above*. Students interested in these programs should read the appropriate departmental descriptions before consulting with the chair of the IGSD about developing an ID major.

The programs below are the established majors administered through IGSD.

TECHNICAL, SCIENTIFIC, AND PROFESSIONAL COMMUNICATION

CO-DIRECTORS: J. Trimbur (HUA), C. Demetry (ME)
ASSOCIATED FACULTY: M. Elmes (MG), K. Lemone (CS), A. Rivera (HUA), R. Smith (HUA)

The program in Technical, Scientific, and Professional Communication (TC) is concerned with the theory, ethics, research, and practice of representing information in a variety of communication media—computer documentation, instruction manuals, hypertext, multimedia presentations, graphics, video, brochures, newsletters, public relations, scholarly writing, journalism, and literary nonfiction. The goal of the TC program is to prepare communication professionals who can bridge the gap between scientists and engineers and the public by presenting technical information in useful and accessible ways.

The TC program is an interdisciplinary major that combines work in written, oral, and visual communication with a strong concentration in a scientific or technical field. In consultation with a faculty program review committee, majors design a plan of study that fulfills the distribution requirements of the program and best suits their intellectual interests and career aspirations.

The TC major provides excellent preparation for students interested in careers in technical and scientific communication, editing, journalism, public relations, education, and publishing and for students who intend to pursue graduate studies in fields such as communication, education, journalism, and rhetoric and composition.

MQP opportunities are available on campus and with local companies, newspapers, public agencies, and private foundations.

Distribution Requirements

TECHNICAL, SCIENTIFIC, AND PROFESSIONAL COMMUNICATIONS	Minimum Units
1. Scientific and/or technical concentration (Note 1)	6
2. Writing and Rhetoric concentration (Note 2)	3
3. MQP	1

NOTES:

1. The student's scientific and/or technical concentration must be a plan of study, approved by the student's program review committee, with a clear underlying rationale in mathematics, basic science, computer science, engineering, and/or management.
2. The Writing and Rhetoric concentration consists of 1 unit in each of the 3 following categories of courses. Courses taken to fulfill these distribution requirements will not include courses that fulfill other degree requirements, such as the Humanities and Arts Sufficiency and the Social Sciences requirement. Exceptions to this restriction, not to exceed 1 unit, must be approved by the student's program review committee, and will be granted only under unusual circumstances.

A. **Written communication** (1 unit)
Recommended courses:
EN/WR 2211 Elements of Writing
EN/WR 3011 Peer Tutoring in Writing
EN/WR 3214 Writing About Disease and Public Health
EN/WR 3216 Writing in the Professions
or equivalent writing courses or ISPs

B. **Rhetoric and communication studies** (1 unit)
Recommended courses:
RH 3111 The Study of Writing
RH 3112 Rhetorical Theory
RH 3211 Rhetoric of Visual Design
or ISP or any of the courses listed in Category A not used to fulfill that requirement.

C. **Electives** (1 unit)
The 1 unit of electives must be coherently defined and approved by the student's program review committee. Students may draw on:
Courses in science, technology, and culture studies (such as AR/ID 3150, CS 3041, CS 3043, EN 2252, EN 3235, HI 2331, HI 2332, HI 2333, HI 2334, HI 3331, SS 2207, SS 2208, or SS 2302);
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;
Management courses.

TEACHER LICENSING

WPI students wishing to be licensed as middle or high school teachers in Massachusetts or states with reciprocation agreements with Massachusetts in the areas of Mathematics, Biology, Chemistry or Physics can do so by passing the Massachusetts Teacher Test (METL) in English and their subject area, taking a Teaching Methods course (ID 310X), performing observation and practice teaching, and taking courses in the appropriate subject matter meeting State guidelines. Students wishing to discuss or pursue this should see Professor John Goulet (MA).

INTERNATIONAL STUDIES

P.H. HANSEN, DIRECTOR
ASSOCIATED FACULTY: W.A.B. Addison (HU), D.B. Dollenmayer (HU),L. Fontanella (HU), P.H. Hansen (HU), M.J. Radzicki (SSPS), K.J. Rissmiller (SSPS), A. Rivera (HU), and J.F. Zeugner (HU)

International Studies prepares men and women for future leadership roles in business and industry, government and public affairs. International Studies integrates WPI's international courses in the humanities and social sciences with its global projects and exchange programs. International Studies courses on-campus prepare students to go abroad. After an experience overseas, students integrate their experiences and explore their career options in a capstone seminar. International Studies at WPI offers a range of options including a minor, major, or double major in International Studies.

MINOR IN INTERNATIONAL STUDIES

The goals of WPI's minor in International Studies are to extend students' global horizons, enhance their disciplinary majors, and expand their career opportunities in the international arena. The program develops a familiarity with global or international issues, an appreciation of cultural differences, and the ability to complete tasks abroad. The minor achieves a basic level of competence in International Studies through a variety of courses, projects, and overseas experiences.

The minor requires a minimum of three units of work related to International Studies as described below. After course work at WPI, students complete their minor through either an international IQP or an international exchange program approved by the Program Review Committee. All students are required to have an international experience off-campus. The program's capstone experience is a Senior Seminar in International Studies. Both options receive the same designation of Minor in International Studies. A student in any major at WPI is eligible to pursue a Minor in International Studies.

Program Requirements for the International Studies Minor

INTERNATIONAL STUDIES IQP OPTION

	Minimum Units
International Core (Note 1)	1
International Electives (Note 2)	1
International IQP (Note 3)	1
International Experience (Note 4)	0
Total	3

INTERNATIONAL STUDIES EXCHANGE PROGRAM OPTION

	Minimum Units
International Core (Note 1)	1
International Electives (Note 2)	2
International Experience (Note 4)	0
Total	3

NOTES:

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

   Courses in the core may not double-count towards other degree requirements such as the Humanities and Arts Sufficiency requirement or the two course requirement in the Social Sciences. If a student has already counted a course from a) or b) for another requirement, they will be required to take additional courses in International Studies so that at least one unit of their minor does not double-count. The capstone seminar should be the final element of a student's minor.
2. International Electives may be selected from among international courses in the Humanities and Social Sciences. They may include any course in European or global history; any course at the intermediate level or above in German or Spanish; any international course in the social sciences; and international courses approved by the Program Review Committee in art history, literature, philosophy and religion. If approved by the Program Review Committee, PQPs for overseas projects may count towards the total. Students may count courses taken to fulfill other degree requirements towards these electives. These electives may not include the MQP or the final 1/3 unit Type 5 IS/P of the Sufficiency Program.
3. International IQP: Students who choose the IQP Option must complete an International IQP. All IQPs completed outside of the United States meet this requirement. If approved by the Program Review Committee, IQPs completed on-campus or at Project Centers in the United States may meet this requirement if the IQP is devoted to an international subject and the student also completes a study abroad experience as described in note 4.
4. International Experience: All International Studies minors are required to have a study abroad experience. Students who choose the Exchange Option must complete an international project, exchange, or internship approved by the Program Review Committee. The study abroad experience should be educational in nature and equivalent in length to at least one WPI term.

For general policy on the minor, see description on pages 26-27.

MAJOR IN INTERNATIONAL STUDIES

The International Studies Major is an interdisciplinary program that combines rigorous preparation in international studies with competence in an area of science, technology, or management. Under the broad umbrella of the International Studies distribution requirements, students will be able to create their own flexible programs to accommodate their interests and career goals. MQPs may be completed on campus or at one of WPI's global project centers. In consultation with the Program Review Committee, students plan a course of study that may focus on a region of the world, or a thematic issue, or an analytical approach to international studies. International Studies majors are well prepared for careers in business, government, and public affairs.

Distribution Requirements for the International Studies Major

REQUIREMENTS	Minimum Units
International Core (Note 1)	1
International Fields (Note 2)	4
International Experience (Note 3)	0
Electives (Note 4)	4
MQP	1
Total	10

NOTES:

1. International Core: One course must be selected from each of these categories:
   a) An introductory course in international history, such as HI 1341 or HI 1313, HI 1321, HI 1322, HI 1323.
   b) A course in understanding cross-cultural differences, such as one of the following: HU 3411 Pro-Seminar in Global Perspectives, or SS 2406 Cross-Cultural Psychology; or SS 1202 Sociological Concepts and Comparative Analysis; or PY 2716 Philosophy of Difference.
   c) HU 4411 Senior Seminar in International Studies.

2. International Fields: Majors complete at least one unit of work in each of the following areas. They must also complete at least one additional unit of work in one of these areas, which will be considered their primary field.
   a) Historical Analysis. These include any courses in European history, world history, or American foreign policy.
   b) Language, Literature, and Culture. These include any course in foreign languages, civilization, and literature offered at WPI or in the Consortium with the prior approval of the Program Review Committee; also courses approved by the Program Review Committee in Art History (e.g. AR 1111, AR 2111), English Literature (e.g. EN 2243, EN 3222), Music History (e.g. MU 2615), or Philosophy and Religion (e.g. RE 2721, RE 2724). Majors who designate Language, Literature, and Culture (LLC) as their primary field may not take courses in a second foreign language unless they have achieved 3000-level proficiency in the first. LLC designees should take most of their courses in a single discipline or in a coherent program approved by the Program Review Committee.
   c) Social Sciences. These include international courses in the social sciences (e.g. SS 1320, SS 2105, SS 2125, SS 2312, SS 2406). Students may count courses taken for the two-course requirement in Social Sciences.
3. International Studies majors are required to have a study-abroad experience. (In very unusual cases exceptions may be made to this requirement but only with prior approval of the Director and Program Review Committee). This abroad experience may take the form of a project, exchange, or internship approved by the Program Review Committee. The study-abroad experience should be educational in nature and equivalent in length to at least one WPI term.
4. Electives may be from any area except Aerospace Studies, Military Science or Physical Education. Double-majors may count as electives courses taken for their other major. Majors who are not completing a double-major are required to complete a two-unit technical sufficiency in an area of science, engineering, or mathematics apart from these electives.

DOUBLE MAJOR IN INTERNATIONAL STUDIES

Students may pursue a double major in International Studies and any area of study at WPI except a major in Humanities and Arts. To pursue the double major, a student must satisfy all of the degree requirements for both disciplines, including an MQP and Distribution Requirements. In addition, the double major in International Studies requires the same distribution of courses in the International Core and International Fields as the major in International Studies and a second MQP in International Studies. Double majors are also required to have an International Experience. Students pursuing the double major in International Studies are not required, however, to complete a Humanities and Arts Sufficiency program.

RECOMMENDATIONS FOR STUDENTS

Students planning an International Studies minor, major, or double major should take their International Core courses in international history and cross-cultural differences before they go abroad. Since many students go off-campus during their Junior year, students should plan to take these Core courses in their Freshman and Sophomore years. Students are also encouraged to take their International Electives before going abroad and on topics that relate to their international experience. The capstone course, HU 4411, Senior Seminar in International Studies, should be the final element of the minor. Therefore, students may enroll in HU 4411 after they have completed all of the other requirements for the International Studies minor. Students planning an International Studies minor may also wish to consider the possibility of completing a double major in International Studies.

INTERNATIONAL EXPERIENCES

An International Experience may take the form of an international IQP or exchange program. Students often plan their international experience in their Sophomore year. All students are advised to consult the list of projects offered at WPI's Global Project Centers. Each fall, the projects and exchange programs for the following year are widely advertised on campus. For information about student exchange programs, see page 234.

Award-winning projects at WPI are frequently on international topics. Recent examples include studies of a workshop for the blind in London, chemical accidents in Bangkok, the social impact of the building code in New Zealand, and the use of biogas in Botswana. International Studies offers the opportunity not only to complete some of the highest quality projects at WPI, but also to offer solutions to some of the most challenging problems in the world.

Students interested in International Studies may ask any member of the Associated Faculty for more information, or they may consult our page on the World Wide Web: http://www.wpi.edu/+IN/.

LAW AND TECHNOLOGY MINOR

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

The Law and Technology Program is an interdisciplinary minor that can be used to supplement a major, introduce students in science and engineering disciplines to legal studies and prepare students to enter law school upon graduation. Students in the program begin their studies with a foundation in legal institutions and analysis and continue with advanced courses that integrate law and technology. A course in professional communication is also required. Students complete their studies with a capstone research activity either in the sixth course or as a separate independent study.

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

1. Two of the following courses in legal fundamentals:
   - HI 2317 Law and Society in America, 1865-1910
   - SS 1310 Law, Courts and Politics
   - SS 2310 Constitutional Law
   - MG 2950 Business Law and Ethics
2. Two of the following courses which integrate law and technology:
   - CE 3022 Legal Aspects in Design and Construction
   - CE 4071 Land Use Development and Controls
   - SS 2311 Legal Regulation of the Environment
   - SS 2313 Intellectual Property Law
   - SS/ID 2314 Cyberlaw and Policy
   - Independent study or experimental courses with the approval of the pre-law advisor
3. One of the following courses in professional communication:
   - EN/WR 2211 Elements of Writing
   - EN/WR 3214 Writing About Disease and Public Health
   - EN/WR 3216 Writing in the Professions
   - RH 3112 Rhetorical Theory
4. One of the following courses undertaken as a capstone experience:
   - SS 2304 Governmental Decision Making and Administrative Law
   - SS 2313 International Environmental Policy

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

Students should review their program of study with the associated faculty and/or pre-law advisor. Students are also encouraged to seek IQP opportunities in Division 52, Law and Technology. See page 46. Note: only one of the two units may be counted toward other college requirements.

For general policy on the Minor, see description on pages 26-27.

MANAGEMENT

M. C. BANKS, HEAD
S. A. JOHNSON, DIRECTOR IE PROGRAM
D. M. STRONG, DIRECTOR MIS PROGRAM

PROFESSORS: M. C. Banks, M. B. Elmes, A. Gerstenfeld, J. T. O'Connor, H. G. Vassallo
ASSOCIATE PROFESSORS: S. A. Johnson, C. J. Kasouf, F. Noonan, D. M. Strong
ASSISTANT PROFESSORS: E. Daneels, H. N. Higgins, E. Loiacono, S. McCoy, J. Mistry, K. Muhkerjee, S. Taylor, O. Volkoff, K. Wilkens, A. Zeng, J. Zhu
ADJUNCTS: G. Heaton, J. Minasian
VISITING FACULTY: J. Sulej

INTRODUCTION

The Department of Management provides undergraduate and graduate management education designed to help aspiring managers and executives understand how to use technology to help organizations and individuals succeed in their business endeavors. Our courses combine a practical component, which helps our students apply what they learn, and a theoretical component, which helps them understand why it works and how to use it in other settings. Many courses include a strong global component to help our students understand business beyond the borders of the United States. Additionally, most courses include a discussion of ethics and force students to wrestle with right and wrong. That our approach is successful is demonstrated in our strong placement record, the above (national) average salaries of many of our graduates, and that within five years of graduation they earn, on average, more than any other WPI graduates in the same class.

We provide a number of educational opportunities for our students. We offer undergraduate majors in Industrial Engineering (IE), Management (MG), Management Engineering (MGE), and Management Information Systems (MIS), and minors in Entrepreneurship, Management, Management Information Systems, and Organizational Leadership. At the graduate level we offer the MBA, MS in Operations and Information Technology, MS in Marketing and Technological Innovation, our combined BS/MBA program, and our graduate certificates in Technology Marketing, Management of Technology, Information Technology, and Electronic Commerce.

OUR STRATEGIC INTENT

To be the premier provider of undergraduate and graduate education focused on the Management of Technology.

OUR MISSION

The Department of Management at WPI is committed to providing education, research, and outreach that focus on:

- leading and managing technology-based organizations;
- integrating technology into the workplace; and
- creating new processes, products, services, and organizations based on technology.

We emphasize:

- innovative and project-based education that integrates the theory and the practice of management, and prepares students to assume positions of leadership in an increasingly global business environment;
- basic scholarship, while also valuing the scholarship of application and the scholarship of instruction; and
- interaction with the business community focused primarily on technological entrepreneurship.

INDUSTRIAL ENGINEERING

Industrial engineers focus on process improvement. The process might be a manufacturing line, where each process step is a physical operation that creates a product, or might involve paper and information, such as the steps required to apply to a particular college for admission. Improvement can mean reducing cost, reducing the time required to complete the process, or reducing the number of errors. To be effective, industrial engineers must combine technical knowledge with concerns about how people fit into the systems they design - skills that organizations need a lot right now. Industrial engineers take a systems view, considering all the resources (people, technology, information) that are part of the process. Industrial engineers find jobs in manufacturing firms, hospitals, transportation firms, and government agencies. An industrial engineer might be in charge of quality on a production line, develop computer models to improve service to patients in a hospital clinic, or work to reduce inventory costs. Many industrial engineers move into supervisory or management positions as their career progresses.

INDUSTRIAL ENGINEERING PROGRAM CHART

Note: This chart summarizes recommendations regarding course selection, sequencing, and timing. Students are encouraged to read the Program Distribution Requirements and Curriculum Guidelines for IE for more complete information. Students are also encouraged to arrange their programs to take advantage of global and cooperative education opportunities.

	FRESHMAN/SOPHOMORE	JUNIOR	SENIOR
COURSE RECOMMENDATIONS	Calculus Sequence MA 1021, MA 1022, MA 1023, MA 1024, MA 2051 Statistics Sequence MA 2611; MA 2612 or MA 2621 H&A Sufficiency Physics/Chemistry Sequence PH 1110, PH 1120, CH 1010; or PH 1110, CH 1010, CH 1020 CS 1005 Start IE Core: MG/IE 2500 MG/IE 3400 MG 2720 Social Science 2 Math/Science Electives	IQP Complete IE Core: MG/IE 2850 MG/IE 2300 MG/IE 3401 MG/IE 3420 or MG/IE 3501 MG/IE 3460 Engineering Basics Outside IE 2 IE Electives: Choices: MG/IE 3405, MG/IE 3420, MG/IE 3450, MG/IE 3501, MG/IE 3720, MG/IE 4410, MG/IE 4460, MG/IE 4720, and OR courses in MA 1Technical Elective Any engineering/science design course (see page 125 for recommendations)	MQP 1 IE Elective 2 Technical Electives At least 3 Free Electives Complete any remaining degree requirements
DEGREE REQUIREMENTS	H&A Sufficiency (2 units)		
		IQP (1 unit)	
	Math/Science (4 units)		
	Industrial Engineering Topics (5 units) (from mid Freshman/Sophomore through Senior)	Industrial Engineering Topics (5 units)	Industrial Engineering Topics (5 units)
			MQP (1 unit)
	Social Science (2/3 units)		
		Free Electives (1 unit)	Free Electives (1 unit)
	Physical Education (1/3 unit)	Physical Education (1/3 unit)	Physical Education (1/3 unit)

At WPI, the IE program is designed to provide students with the tools to spearhead process improvement efforts and the knowledge to implement and employ new technologies. Industrial engineering majors at WPI complete courses in three major categories: (1) the basic mathematics and science courses that are the foundation for all engineering disciplines, (2) core courses that address the tools that industrial engineers use to effect process improvements, including such things as computer simulation and theories of human behavior, and (3) elective courses that can be tailored to your career objectives.

The Major Qualifying Project (MQP) is an integral part of the education of our majors. In addition to satisfying a significant graduation requirement, the MQP must be focused on industrial engineering design. It is typically performed for a business organization. These two elements of our approach to MQPs result in a very valuable learning experience for all of our students. Examples of the MQP for industrial engineering majors include:

- Lean Manufacturing Cell Development at Teradyne
- Process Improvements for the CFM56-3 at General Electric Engine Services
- Reduction of Quotation Process Cycle Time at Westfield Gage
- Use of SPC Tools in Film Manufacturing
- Quality Function Deployment for Primary Care Physician's Office

MISSION STATEMENT

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 core industrial engineering skills with modern 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.

EDUCATIONAL OBJECTIVES

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

(1) ***Industrial Engineering Knowledge and Design Skills.*** Graduates should be able to support operational decision making and design solutions to address the complex and changing industrial engineering problems faced by organizations, using modern concepts and technology.

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

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

PROGRAM OUTCOMES

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

(1) *Industrial Engineering Knowledge and Design Skills*

(a) An ability to identify, formulate, and solve industrial engineering problems.
(b) An ability to design and conduct experiments, as well as to analyze and interpret data.
(c) An ability to design and improve integrated systems of people, materials, information, facilities and technology.
(d) An ability to apply core industrial engineering concepts, using the updated techniques, skills and tools necessary for industrial engineering practice.
(e) The broad education necessary to understand the impact of engineering solutions in a societal context.
(f) An ability to apply knowledge of mathematics, including statistics as well as integral and differential calculus.
(g) An understanding of fundamental physical laws.

(2) *Communication Skills*

(h) An ability to communicate effectively.

(3) *Teamwork and Leadership Skills*

(i) An ability to work effectively on multi-disciplinary teams.
(j) An understanding of professional and ethical responsibility.
(k) A recognition of the need for and an ability to engage in life-long learning.
(l) A knowledge of contemporary issues.
(m) An understanding of global issues.
(n) An understanding of change management in organizational settings.

Program Distribution Requirements for Industrial Engineering Major (IE)

The normal period of residency at WPI is 16 terms. In addition to the WPI requirements applicable to all students (see page 22), students wishing to receive the ABET accredited degree designated "Industrial Engineering" must complete a minimum of 10 units of study in the areas of mathematics, basic science, and engineering topics as follows:

Requirements	Minimum Units
1. Mathematics and Basic Science (Notes 1, 2)	4
2. Industrial Engineering Topics (including the MQP) (Notes 3,4)	6

NOTES:

1. Mathematics must include differential and integral calculus, ordinary differential equations, and 2/3 units in probability and statistics.
2. Basic Science must include both chemistry and physics, with a minimum of two courses in either.
3. Must include 1/3 unit of Capstone Design Experience.

4. Industrial Engineering Topics must include courses in the following three topic areas.
   a. 3 units of industrial engineering core courses, including 1/3 unit in each of the following 9 areas: engineering basics outside industrial engineering, deterministic operations research methods, process design, production planning and control, simulation, stochastic methods in operations research, information systems design, financial modeling and organizational science.
   b. 1 unit in Industrial Engineering electives. 3000/4000 level MG/IE courses and Operations Research courses in Mathematics qualify with the exception of courses in financial modeling and organizational science.
   c. 1 unit in technical electives. Industrial Engineering electives and any other Engineering Science/Design courses qualify.

Curriculum Guidelines for IE

Recommendations for complying with program distribution requirements (10 units) are described below. Students are encouraged to use a Program Tracking Sheet to plan their program and document their progress toward meeting degree requirements. Program tracking sheets are available on the IE web page or in the Management Department Office. To earn a Bachelor of Science (B.S.) degree in Industrial Engineering, students must complete 15 units of coursework. In addition to the requirements below, one must complete the Sufficiency requirement (2 units), the Interactive Qualifying Project (1 unit), free electives (1 unit), social sciences (2/3 unit), and physical education (1/3 unit). Students without prior programming experience are encouraged to take CS 1005 in their freshman or sophomore year.

(1) Mathematics and Basic Science (4 units)

Mathematics requirements include differential and integral calculus, ordinary differential equations, and 2/3 units probability and statistics. Mathematics requirements can be satisfied by taking MA 1021, MA 1022, MA 1023, MA 1024, MA 2051, MA 2611, and MA 2612. Other recommended courses include: MA 2071, courses in probability and statistics, and courses in numerical analysis.

Basic science courses can be elected in chemistry, physics, biology, or geology. Students must take both chemistry and physics, with a minimum two-course sequence in one of these areas.

(2) Industrial Engineering Topics (5 units)

Students must choose 1 course in each of nine core areas, then choose one unit of industrial engineering and one unit of technical electives. Students who plan to take the Engineering Fundamentals examination in their senior year or to pursue a graduate degree in an engineering field should select their additional unit of work from the engineering science courses suggested under *Technical Electives.*

Industrial Engineering Core (3 units)

Choose one course from each area of the following nine areas:

- *deterministic operations research methods:* MG/IE 2500 - Management Science I or MA 3231- Linear Programming
- *process design:* MG/IE 3400 - Production System Design or MG/IE 3405 - Work Systems and Facilities Planning
- *production planning and control:* MG/IE 3401 - Production Planning and Control
- *simulation:* MG/IE 3460 - Simulation Modeling and Analysis
- *stochastic methods:* MG/IE 3420 - Quality Planning, Design, and Control or MG/IE 3501 - Management Science II
- *information systems design:* MG 2720 - Business Application Development Tools or MG 2710 - Business Application Platforms
- *financial modeling:* MG/IE 2850 - Engineering Economics
- *organizational science:* MG/IE 2300 - Organizational Science Foundation or MG/IE 3351 - Organizational Science Management of Change
- *engineering basics outside IE*: the engineering basics course is designed to allow students to explore some of the fundamental engineering knowledge associated with either manufacturing or service systems. Depending on the systems that are most interesting to them, it is recommended that students select one course from the following lists:

Manufacturing: ES 1310 - Engineering Design Graphics, ME1800 - Manufacturing Processes, ES 2001 - Introduction to Materials Science, and ME 2820 - Materials Processing

Service systems: EE 2011 - A Project-Oriented Introduction to Electrical and Computer Engineering, EE 3601 - Principles of Electrical Engineering, CS 2011 - Introduction to Machine Organization and Assembly Language, CS 2135 - Programming Language Concepts, and CS 4032/MA 3257 - Numerical Methods for Linear and Nonlinear Systems.

Industrial Engineering Electives (1 unit)

To achieve depth in their IE program, students are required to take one additional unit of advanced IE courses. Students may choose to focus in operations design and planning, information systems design, or operations research, or to elect a more general program by selecting courses from several areas. A course counted toward the IE core cannot be counted again as an elective. Industrial Engineering courses (listed with an MG/IE designation) and Operations Research courses in Mathematics at the 3000/4000 level qualify with the exception of courses in financial modeling and organizational science.

Technical Electives (1 unit)

Industrial Engineering electives and other Engineering Science/Design courses qualify. Courses that can be counted as Engineering Science/Design are described on page 35.

For students planning on taking the Fundamentals of Engineering examination, the following courses are recommended:

EE 3601 - Principles of Electrical Engineering
ES 2001 - Introduction to Materials Science
ES 2501 - Introduction to Static Systems
ES 2503 - Introduction to Dynamic Systems
ES 3004 - Fluid Mechanics

DEPARTMENT OF MANAGEMENT

SAMPLE STUDENT PROGRAM WITH OVERSEAS IQP AND AN INTERNSHIP

FIRST YEAR	SECOND YEAR	THIRD YEAR	FOURTH YEAR
Sufficiency 1	*(apply in Fall for IQP abroad next year)*	IQP (overseas project center)	Major Course 4
Sufficiency 2	Sufficiency 5	MG 3400	Major Course 5
Sufficiency 3	Sufficiency 6	MG 3600	Major Course 6
Sufficiency 4	MG 1100 (A term)	MG 3700	MQP
MA 1021	MG 2101 (B term)	Major Course 1	Free Elective
MA 1022	MG 2200	Major Course 2	Free Elective
MA 2611	MG 2300	Major Course 3	Free Elective
MA 2612	MG 2500	MG Elective (3000 or 4000)	Free Elective
SS 1110	MG 2950	MG Elective	Free Elective
SS 1120	CS 1005	MG Elective	
Science 1	PE 3		
Science 2	PE 4		
PE 1	Internship		
PE 2			

SAMPLE STUDENT PROGRAM WITH NO OFF CAMPUS COMPONENTS

FIRST YEAR	SECOND YEAR	THIRD YEAR	FOURTH YEAR
Sufficiency 1	Sufficiency 5	IQP 1	Major Course 4
Sufficiency 2	Sufficiency 6	IQP 2	Major Course 5
Sufficiency 3	MG 1100 (A term)	IQP 3	Major Course 6
Sufficiency 4	MG 2101 (B term)	MG 3400	MQP
MA 1021	MG 2200	MG 3600	Free Elective
MA 1022	MG 2300	MG 3700	Free Elective
MA 2611	MG 2500	Major Course 1	
MA 2612	MG 2950	Major Course 2	
SS 1110	CS 1005	Major Course 3	
SS 1120	Free Elective	MG Elective (3000 or 4000)	
Science 1	Free Elective	MG Elective	
Science 2	Free Elective	MG Elective	
PE 1	PE 3		
PE 2	PE 4		

SAMPLE STUDENT PROGRAM INCLUDING SUMMER AND CO-OP

FIRST YEAR	SECOND YEAR	THIRD YEAR	FOURTH YEAR
Sufficiency 1	Sufficiency 5	IQP 1	Major Course 4
Sufficiency 2	Sufficiency 6	IQP 2	Major Course 5
Sufficiency 3	MG 1100 (A term)	IQP 3	Major Course 6
Sufficiency 4	MG 2101 (B term)	MG 3400	MQP
MA 1021	MG 2200	MG 3600	MG Elective
MA 1022	MG 2300	MG 3700	Free Elective
MA 2611	MG 2500	Major Course 1	MG 3000- or 4000-level elective
MA 2612	MG 2950	Major Course 2	
SS 1110	CS 1005	Major Course 3	
SS 1120	MG Elective	Cooperative Education Experience (D- and E-Terms)	
Science 1	Free Elective		
Science 2	Free Elective		
PE 1	PE 3		
PE 2	PE 4		

FIRST SUMMER
3 Free Electives

(3) Major Qualifying Project (1 unit)
The MQP is expected to provide a capstone design experience for industrial engineering majors. If the MQP does not fulfill this 1/3 unit requirement, the student should speak with the Industrial Engineering Program Director to determine an appropriate method for fulfilling this requirement.

MANAGEMENT (MG)

The Management major at WPI is what many colleges and universities would call "General Business." Our approach is to provide a broad understanding of business through what we refer to as Foundation Courses. These include such courses as Financial and Managerial Accounting, Marketing Management, and Operations Management. On top of the Foundation Courses, each student selects six related courses as the focus of their advanced work. These courses should be selected from the MG list found in the section, Curiculum Guidelines For MG, MGE, MIS. Courses not on this list must be approved by your academic advisor and the Department's Undergraduate Policy & Curriculum Committee (UPCC). This latter option permits you to develop a plan of study that is tailored to your career objectives. Career opportunities for management students can be found in banking and finance, manufacturing management, marketing and sales, research and development, human resources, public or not-for-profit sector management, and many other occupations.

The Major Qualifying Project (MQP) is an integral part of the education of our MG majors. In addition to satisfying a significant graduation requirement, the MQP must be focused in the student's specific focus area. It is typically performed for a business organization. These two elements of our approach to MQPs result in a very valuable learning experience for all of our students. Examples of the MQP for Management majors include:

- Improving a city's permitting process,
- Developing an inventory control system for a university athletics department,
- Evaluating risk in mergers, and
- Reengineering human resources at a hospital.

PROGRAM 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.

MANAGEMENT ENGINEERING (MGE)

Management Engineering at WPI combines the best of a business degree with a technical focus. MGE majors develop a broad understanding of business through what we refer to as Foundation Courses. These include such courses as Financial and Managerial Accounting, Marketing Management, and Operations Management. On top of the Foundation Courses, each student selects six related courses as the focus of their advanced work. These courses should be selected from the MGE list found in the section, Curiculum Guidelines For MG, MGE, MIS. Courses not on this list must be approved by your academic advisor and the Department's Undergraduate Policy & Curriculum Committee (UPCC) and usually come from electives in the Department or from areas such as Engineering, Mathematics, or Science. Career opportunities for Management Engineering majors are quite varied. While many become engineers in the focus area (Industrial Engineering, for example), many join management training programs or accept sales positions with technological firms.

The Major Qualifying Project (MQP) is an integral part of the education of our MGE majors. In addition to satisfying a significant graduation requirement, the MQP must be focused in the student's specific focus area. It is typically performed for a business organization. These two elements of our approach to MQPs result in a very valuable learning experience for all of our students. Examples of the MQP for Management Engineering majors include:

- Evaluating Six Sigma,
- Quality function deployment in a healthcare setting,
- Ergonomic evaluation of a manufacturing work center, and
- Evaluation of leased lines and alternative solutions.

PROGRAM OBJECTIVES
Objectives of the Management Engineering Major are:

To prepare students for management challenges in key areas that increasingly require proficiency in the technical aspects of business such as production and service operations.

To provide the knowledge and skills necessary to succeed professionally, including literacy in a technical field, a broad understanding of management issues, written communication, oral presentation, decision-making, and leadership skills required to create new and improved products, processes and control systems.

To develop student abilities necessary for continued career growth including:

- the ability to integrate theory and practice and to apply knowledge of technical issues with the foundations of management;
- the ability to integrate technology and change into existing organizations;
- the ability to think critically and analytically, to define and solve business problems, work in teams, and think globally; and
- the ability to learn new skills in response to changing professional requirements.

MANAGEMENT INFORMATION SYSTEMS (MIS)

Like our other major programs in the Department of Management, the Management Information Systems program combines a broad understanding of business, through what we refer to as Foundation Courses, with specialized education in Information Systems. Foundation Courses include such areas as Financial and Managerial Accounting, Marketing Management, and Operations Management. On top of the Foundation Courses, each student selects six MIS courses as the focus of their advanced work. These courses should be selected from the MIS list found in the section, Curiculum Guidelines For MG, MGE, MIS. Courses not on this list must be approved by your academic advisor and the Department's Undergraduate Policy & Curriculum Committee (UPCC) and usually come from electives in the Department or from areas such as Computer Science or Electrical and Computer Engineering.

Based on the rigorous IS '02 Guidelines for MIS programs, our MIS courses cover such areas as business application development tools, data management, and telecommunications, among others. This program helps students develop strong analytical, problem solving, and communication skills, and a solid understanding of business and computing. Many of our MIS majors join international consulting firms upon graduation, while others take entry-level positions as programmer-analysts, business analysts, end-user support staff, and eventual management training positions in high-technology businesses.

The Major Qualifying Project (MQP) is an integral part of the education of our MIS majors. In addition to satisfying a significant graduation requirement, the MQP must be focused in the student's specific focus area. It is typically performed for a business organization. These two elements of our approach to MQPs result in a very valuable learning experience for all of our students. Typical MQPs for MIS majors include:

- Developing a kiosk system,
- A web-based archeological stratification tool,
- Creating a help desk system, and
- Measuring data quality.

Clients have included both small and large companies as well as manufacturing businesses, financial firms, consulting firms, public sector organizations, and university departments.

PROGRAM OBJECTIVES

The objectives of the Management Information Systems Major are:

To prepare students for positions involving the design and deployment of business applications using a wide variety of advanced information technologies, especially in high technology business, consulting, and service firms, in either start-up or established environments, and to prepare students for rapid advancement to project management and other management positions.

To provide the knowledge and skills consistent with the professionally accepted IS curriculum guidelines. Specifically, this includes providing knowledge and skills related to:

- business application development tools;
- database, web-based and networked applications;
- integrating IT into existing organizations through managing and leading systems analysis and design projects;
- communicating effectively via written and oral presentations.

To develop student abilities necessary for continued career growth including:

- the ability to integrate theory and practice and to apply knowledge of information technology issues with the foundations of management;
- the ability to integrate technology and change into existing organizations;
- the ability to think critically and analytically, to define and solve business problems, work in teams, and think globally; and
- the ability to learn new skills in response to changing professional requirements.

Program Distribution Requirements for Management Degrees (MG, MGE, and MIS)

Requirements (MG, MGE, MIS)	Minimum Units
1. Management Foundation (Note 1)	11/3
2. Mathematics (Note 2)	4/3
3. Basic Science	2/3
4. Management Major (Note 3)	6/3
5. Management Electives (Note 4)	3/3
6. Computer Science	1/3
7. MQP (Note 5)	3/3

NOTES:

1. The Management Foundation must cover the foundation knowledge in the management functional areas, including at least 1/3 unit of financial accounting, managerial accounting, financial management, organizational science, deterministic management science, operations management, marketing management, information systems management, microeconomics, macroeconomics, and business law and ethics.
2. Mathematics must include 2/3 units of calculus and 2/3 units of statistics.
3. The Management Majors (other than IE) must comprise a department-approved integrated set of courses covering a specific area of: management, science, engineering or mathematics for MGE; computer science or information systems for MIS; management, social sciences, or humanities for MG.
4. Management electives must include at least 1/3 unit of 3000/4000 level MG courses. The remaining 2/3 units specified in the requirement may be satisfied with courses from Mathematics, Basic Science, Computer Science, Management, or Social Science, but excluding courses MG 1250, and MG/IE 2850.
5. Courses may not be counted more than once in meeting the departmental distribution requirements. The total number of MG (and/or MG/IE) units may not exceed 50% of the total number of units earned for the degree.

Curriculum Guidelines for MG, MGE, MIS

Specific course recommendations for complying with the distribution requirements are given below. These guidelines are intended to offer flexibility while meeting minimal standards in preparing for careers in MG, MGE, or MIS.
MATHEMATICS-minimum of 4/3 units is required, with 2/3 units in calculus and 2/3 units in statistics. For most students, MA 1021, MA 1022, MA 26111, and MA 2612 will be appropriate.
BASIC SCIENCE-minimum of 2/3 unit is required, where all courses with the prefix PH, CH, and BB, as well as GE 2341 and GE 3050, qualify.
COMPUTER SCIENCE-minimum of 1/3 unit is required where all courses with the prefix CS qualify (except CS 3043). Either CS 1005 or CS 1006 is recommended.
MANAGEMENT-minimum of 4 units is required with 2/3 units in accounting and 2/3 units in economics, and 1/3 unit from each of the 8 remaining management categories designated below. Recommended courses are listed. These courses represent the basic courses in each functional area of Management. It is recommended that courses SS 1100 and SS 1120 be taken during the First Year.

Management Foundation Coursework

Accounting	MG 1100 and MG 2101
Economics	SS 1110 and SS 1120
Finance	MG 2200
Organizational Science	MG/IE 2300
Quantitative Methods	MG/IE 2500
Business Law & Ethics	MG 2950
Production	MG/IE 3400
Marketing	MG 3600
Information Systems	MG 3700

3000- or 4000-level MG elective

MAJOR-minimum of 2 units of integrated course work is required for students majoring in Management, MIS, or Management Engineering. Other courses may be used but must be approved by the student's academic advisor and the Department's Undergraduate Policy & Curriculum Committee early in the student's program.

MG
Complete six (6) of the following: MG 1900, MG 2250, MG 2260, MG 2720, MG/IE 3351, MG/IE 3400 OR MG/IE 3401, MG 3640, MG 3651, MG 3720, MG 3910, MG 3920, MG 4151, MG 4364, MG 4365, MG 4930. Students wishing to use other courses as part of the Management major should secure the approval of their MG academic advisor and the Department of Management's Undergraduate Policy & Curriculum Committee (UPCC).

MGE
Complete six (6) of the following: MG 2720, MG/IE 3351, MG/IE 3400 OR MG/IE 3401, MG/IE 3420, MG/IE 3501, MG 3640, MG 3651, MG 3720, MG 4151, MG 4364, MG 4365, MG/IE 4410. Students wishing to use other courses as part of the MGE major should secure the approval of their MGE academic advisor and the Department of Management's Undergraduate Policy & Curriculum Committee (UPCC).

MIS
Management Information Systems
MG 2720, MG/IE 3720, MG 3740, MG/IE 4720, and two of the following: MG 4740, MG 4750, CS 2005, CS 2011, CS 3041. Students wishing to use other courses as part of the MIS major should secure the approval of their MIS academic advisor and the Department of Management's Undergraduate Policy & Curriculum Committee (UPCC).
BREADTH-In addition to the guidelines listed above for Mathematics, Basic Science, Computer Science, and Management, the departmental distribution requirements call for an additional 2/3 units, which may be distributed across these categories as well as social science.

MANAGEMENT NONMAJOR INFORMATION
Often the courses of the Department will be used as a small portion of other degree programs. Since management background is increasingly important, the nonmajor function is selected by many students. Areas for either exposure or focus for the non-management major include marketing, accounting, finance, enterpreneurship, operations, and organization science. Special topics or projects can be arranged on a limited basis. Care should be taken that MG and MG/IE courses do not exceed 25 percent of the total units taken for a degree.

FIVE-YEAR DUAL DEGREE BS/MBA PROGRAM
The combination of a technical undergraduate degree and a graduate degree in business has been cited by many experts as the ideal educational preparation for a career in private industry. For that reason, the Department of Management offers the opportunity for obtaining dual degrees (i.e., the B.S. degree in engineering or science and the Master of Business Administration, MBA). The dual-degree program can be completed within five years, however, the program is demanding, and curriculum planning with the student's advisor and the Department of Management should start by the beginning of the student's third year at WPI at the very latest.

Only registered WPI undergraduates majoring in an engineering (excluding Management Engineering) or science area may enter the Combined B.S./MBA Program. A separate and complete application to the MBA program must be submitted. Admission to the Combined Program is determined by the faculty of the Department of Management. The student should begin the curriculum planning process at the time he/she commences his/her undergraduate studies to ensure that all of the required prerequisite undergraduate courses are completed within the student's four years of undergraduate study. It is recommended that the MBA application be submitted no later than the beginning of the student's Third Year of undergraduate study. A student in the Combined Program continues to be registered as an undergraduate until the bachelor's degree is awarded.

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

MG 1100	*Financial Accounting*
MG 2200	*Financial Management*
MG/IE 2300	*Organizational Science*
MA2611	*Applied Statistics I*
MA2612	*Applied Statistics II*
MG/IE 3400	*Production System Design*
MG 3600	*Marketing Management*
MG 3700	*Information Systems Management*
SS 1110	*Introductory Microeconomics*
SS 1120	*Introductory Macroeconomics*

To obtain a bachelor's degree via the Combined Program, the student must satisfy all requirements for the bachelor's degree, including distribution and project requirements.

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

MG 511	*Interpersonal and Leadership Skills for Technological Managers*
MG 512	*Creating and Implementing Strategy for Technological Organizations*
MG 513	*Creating Processes in Technological Organizations*
MG 514	*Business Analysis for Technological Managers*
MG 515	*Legal and Ethical Context of Technological Organizations*
MG 516	*Graduate Qualifying Project (GQP)*

12 Elective Credits

A student in the Combined Program may, with prior approval, apply the equivalent of a maximum of 12 graduate credits from the same courses toward both the bachelor's and MBA degrees. Students in the Combined Program may not take graduate-level management courses prior to their Fourth Year of undergraduate study, and then only provided the corresponding prerequisites have been satisfied. Students in the Combined Program may use advanced undergraduate major or elective courses (generally classified as 4000-level courses) to satisfy graduate degree elective requirements. The Department of Management decides which courses may be used in this way. Faculty members teaching these advanced undergraduate courses may impose special requirements, appropriate to an undergraduate course being used for graduate credit, on Combined Program students.

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

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

COURSE AREAS AND NUMBERING

The second digit of undergraduate Management course numbers denotes the subject area as follows:

0 - General
1 - Accounting
2 - Finance
3 - Organizational Science
4 - Operations Management and Industrial Engineering
5 - Management Science
6 - Marketing
7 - Management Information Systems
8 - Managerial Economics
9 - Entrepreneurship and Special Topics

ENTREPRENEURSHIP MINOR

All around the world people are starting their own new business ventures. With its strong heritage of entrepreneurship, 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 a $50,000 business plan competition, the WPI Dinner with Entrepreneurs Series, the WPI chapter of CEO (Collegiate Entrepreneurs Organization), the monthly WPI Venture Forum meetings, a variety of speakers and other events related to entrepreneurship, and access to a wide network of entrepreneurs from around the U.S. and abroad.

The Minor in Entrepreneurship is available to all students except those majoring in MG, MGE, or MIS, who may take the courses as part of their major or as free electives.

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

1. Complete the following course:
   MG/IE2850 Engineering Economics
2. Complete two (2) from the following list:
   MG1100 Financial Accounting **OR**
   MG2101 Management Accounting
   MG2950 Business Law & Ethics
   MG3400 Production System Design
   MG3600 Marketing Management
   MG3700 Information Systems Management
3. Complete the following three courses, preferably in order:
   MG3910 Identifying & Evaluating New Venture Opportunities
   MG3920 Planning & Launching New Ventures
   MG4930 Growing and Managing New Ventures

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

For general policy on the Minor, see the description on pages 26-27.

MANAGEMENT MINOR

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 Management Minor offers students (other than MG, MGE, or MIS majors, who may take the courses as part of their major or as 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 Management Minor, a student must complete two units of work in the Management Area, typically through course work with the following distribution:

1. **One course** from the Social Science Economics area. Any course with course designation SS#1## will qualify.
2. **Three courses** from the group of courses:
   a. MG1900 Introduction to Business in an International Environment **O**R MG/IE 2300 Organizational Science
   AND
   b. MG1100 Financial Accounting **OR** MG2101 Management Accounting
   AND
   c. One 2000-level course with prefix MG or MG/IE
3. One 3000 or 4000-level course with prefix MG or MG/IE
4. Capstone Experience MG4930:

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

For general policy on the Minor, see the description on pages 26-27.

MANAGEMENT INFORMATION SYSTEMS MINOR

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

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

1. **One course** from the group of courses:
   MG1900: Introduction to Business in an International Environment **OR**
   MG1100: Financial Accounting **OR**
   MG2101: Management Accounting **OR**
   MG/IE2300: Organizational Science
2. **Two CS courses, or their equivalents, from the following courses:**
   CS1005: Introduction to Programming in C
   CS1006: Introduction to Programming in Java
   CS2005: Techniques of Programming
3. **Two courses** from the group of courses:
   MG 3700: Information Systems Management
   MG/IE 3720: Management of Data
   MG/IE 3740: Organizational Application of Telecommunications
4. **Capstone Experience**
   MG/IE 4720: Systems Analysis and Design

Course MG/IE 4720 is a project-oriented course designed to prepare MIS students and minors for actual information systems design work in business and industry. The course builds and uses MIS concepts for the sound and efficient design of information systems.

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

For general policy of the Minor, see the description on pages 26-27.

ORGANIZATIONAL LEADERSHIP MINOR

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

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

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

2. **Select one of the following:**
   SS 1401 Introduction to Cognitive Psychology
   SS 1402 Introduction to Social Psychology
   SS 2406 Cross-Cultural Psychology: Human Behavior in Global Perspective
3. **Required Capstone Experience**
   MG 4365 Leadership in Groups and Organizations
   Note: The minor in Organizational Leadership may not be taken by students majoring in MG, MGE, or MIS. These students may take the courses as part of their major or as free electives, as appropriate.

For general policy on the Minor, see the description on pages 26-27.

MANUFACTURING ENGINEERING

DIRECTOR: C. A. Brown
PROFESSORS: D. Apelian, I. Bar-On, C. A. Brown, R. D. Sisson, J. M. Sullivan, Jr.
ASSOCIATE PROFESSORS: S. Johnson, M. M. Makhlouf, Y. Rong, S. Shivkumar,
ASSISTANT PROFESSOR: M. Fofana
ADJUNCT ASSISTANT PROFESSOR: W. Weir
LECTURERS: P. D. Cotnoir, K. Stafford

INTRODUCTION

The Manufacturing Engineering Program a multidisciplinary program, relying on faculty and equipment of the departments of Computer Science, Electrical and Computer Engineering, Management, and Mechanical Engineering. Manufacturing Engineering is home to the Robotics Lab, Computer-aided Manufacturing Lab, Machine Dynamics Lab, Surface Metrology Lab, and Haas Technical Center for Computer-controlled Machining.

Manufacturing Engineering integrates basic knowledge of materials, design, processes, computers, engineering analysis, and systems design. This knowledge is used to design, build, operate, and manage production systems. Manufacturing Engineering encompasses a wide range of areas from basic research to technical management. At WPI, Manufacturing Engineers may be involved through courses and MQPs in a wide range of topics including:

Computer-aided Design (CAD)
Computer-aided Manufacturing (CAM)
Surface Metrology
Manufacturing Processes (Casting, Welding, Machining, Grinding)
Industrial Robotics
Simultaneous/Concurrent Engineering
Lean Manufacturing
CNC Machining
Fixturing
Machine Dynamics
Value Engineering
Axiomatic Design
Materials Programming
Heat Treatment

A scientific "high technology" basis for Manufacturing Engineering is evolving. The MFE program is designed to lace WPI students at the leading edge of this evolution.

BACHELOR OF SCIENCE IN MANUFACTURING ENGINEERING

Manufacturing Engineering students are highly sought by industry, earning more on the average than other engineers do. Manufacturing expertise is essential to all industrialized, developing and even post-industrialized societies.

Manufacturing Engineering studies give a solid understanding of the principles of production systems, processing, manufacturability, and quality that can be applied to a wide variety of products, traditional and non-traditional products, such as aircraft, cars, robots, e-business, software, service, and information.

BACKGROUND

Manufacturing Engineering was the first engineering discipline taught at WPI, supporting for well over a century the technological base of one of the most important manufacturing regions in the world. Central Massachusetts is one of the cradles of the Industrial Revolution.

Manufacturing in Massachusetts has been of critical strategic importance for America since the beginning of the boycott of British goods that preceded the War of Independence. The manufacturing industry in Massachusetts began what is known around the world as the American System for mass production.

New England, Massachusetts and Worcester County continue to lead the nation and world in many critical manufacturing technologies.

In the 1980's WPI appropriately became one the first schools in the country to offer an ABET accredited BS degree in Manufacturing Engineering (at that time called "Advanced Manufacturing Systems Engineering").

WPI also was one of the first schools in the country to grant a Ph.D. degree in Manufacturing Engineering. Currently WPI offers three degrees in Manufacturing Engineering, including an M. S. Manufacturing Engineering is also one of the seven concentrations in Mechanical Engineering.

Program Distribution Requirements for the Manufacturing 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 degree designated "Manufacturing Engineering" must satisfy certain distribution requirements:

Requirements	Minimum Units
1. Mathematics and Basic Science (Notes 1,2)	4
2. Engineering Science and Design (including the MQP) (Note 3,4)	6

Notes:
1. Mathematics must include differential and integral calculus and differential equations.
2. Science must include both chemistry and physics with a minimum of two courses in either.
3. At least one unit from each of the following areas is required:
   A. Materials and Processes
   B. Product Engineering
   C. Computer Control and Manufacturing Systems
   D. Production Systems Engineering
4. Must include 1/3 unit of Capstone Design Experience.

MANUFACTURING ENGINEERING PROGRAM CHART

BACKGROUND

4 Units

MATHEMATICS	**SCIENCE
*MA 1021	CH 1010
*MA 1022	CH 1020
*MA 1023	PH 1110
*MA 1024	PH 1120
*MA 2051	PH 1130
MA 2071	PH 1140
MA 2611	BB 1001
MA 2612	BB 1002
MA 2621	
MA 3831	
MA 3832	
MA 4631	

* Mathematics requirements include differential and integral calculus and ordinary differential equations. Additional work is strongly encouraged in one or more of the subjects of probability and statistics, linear algebra, and numerical analysis.

** Science requirements include chemistry and physics with at least a two course sequence in either.

1/3 Unit

PHYSICAL EDUCATION
see page 152

2/3 Units

SOCIAL SCIENCE
see page 159

2 Units

H&A SUFFICIENCY
see page 54

1 Unit

INTERACTIVE QUALIFYING PROJECT (IQP)
see page 39

1 Unit

FREE ELECTIVE
Refer to catalog

MANUFACTURING ENGINEERING

6 Units (Divided approximately 2:1 between Engineering Science: Design)

	1 Unit	1 Unit	1 Unit	1 Unit
	MATERIALS & PROCESSES	PRODUCT ENGINEERING AND TOOL DESIGN	COMPUTER CONTROL & MANUFACTURING SYSTEMS	PRODUCTION SYSTEMS ENGINEERING
One unit per area required	ES 2001	ES 2501	EE 3601	MG/IE 2850
	ME 1800	ES 2502	ES 3011	MG/IE 3400
	ME 2820	ES 2503	ME 3820	MG/IE 3401
	ME 4821	ME 3320	ME 4815	MG/IE 3420
Electives	ME 3023	ES 1310	EE 2011	MG/IE 2500
	ME 3825	ES 3323	CS 2005	MG/IE 3405
	ME 4813	ME 3310	CS 3013	MG/IE 3450
	ME/BE 4814	ME 3311	CS 3431	MG/IE 3501
	ME 4816	ME 3321	CS 4032	MG/IE 3760
	ME 4822	ME 4320	CS 4033	MG/IE 4460

1 Unit Emphasizing Design

MAJOR QUALIFYING PROJECT (MQP)

PLANNING A PROGRAM IN MANUFACTURING ENGINEERING

The MFE program is constructed in a manner similar to other engineering programs. Background and competence is developed in mathematics and the basic sciences. Other WPI requirements, including the Humanities and Arts Sufficiency, social science, and IQP, must be completed. Expertise in the four areas of Manufacturing Engineering is developed. Finally, the MQP, a capstone engineering design project that integrates previous WPI education, is completed.

The chart is intended to assist in student planning. The units listed indicate minimum units required. See page 133.

Although the courses listed are appropriate for most students, it is possible to develop programs using other WPI courses. Since the MFE program is multidisciplinary in nature and has a wide range of electives, student programs should be developed in consultation with their academic advisor and the director of the Manufacturing Engineering Program.

MANUFACTURING ENGINEERING FAST TRACK: BS IN MFE IN 3 YEARS, MS IN 4 YEARS

The program is designed to make it possible for good students to complete the BS in MFE in three years. You will need to use E-terms for courses and project work, and to plan on some overloading. Additionally, through the BS/MS program, it is possible to add a MS in one more year. The planning for this program should be completed before the end of D term in the first year. See your advisor or the director of the Manufacturing Engineering Program for details.

ADDING MINORS IN OTHER AREAS: COMPUTER SCIENCE, MANAGEMENT, MATERIALS ENGINEERING, STATISTICS

Adding one of these minors can be an excellent way to get more out of your college experience and make your resume stand out. Because Manufacturing Engineering is an integrating discipline, accessing course work from other departments and programs, it can relatively easy for MFE majors to add a minor in Computer Science, Management, Materials Engineering, or Statistics. One unit of credit can be double counted for the MFE major and one of the minors. The other unit for he minor can come from the free electives. See the descriptions for the minors under their respective programs.

FOUR- OR FIVE-YEAR DUAL-DEGREE BS/MS PROGRAM

Outstanding undergraduate students in the B.S. program in Manufacturing Engineering and the other engineering and science programs at WPI are encouraged to apply for the four- or five-year BS/MS program in Manufacturing Engineering. This dual-degree program can be completed in five years; however, the program is demanding and curriculum planning with the student's academic advisor and the Director of Manufacturing Engineering should start during the third year at WPI in order to meet both degree requirements. (See "Combined Bachelor's/Master's Program" on page 242, and contact the Director of Manufacturing Engineering for details.)

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 problems that will challenge them in their careers. Most engineers are involved directly or indirectly with manufacturing or manufacturing principles. Manufacturing expertise is essential to all industrialized, developing and even post-industrialized societies. The objective of the minor in manufacturing will be to give the students a solid understanding of the principles of production, processing, manufacturability, and quality that can be applied to a wide variety of products, including non-traditional products, such as software, service and information.

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

I. **1 unit** of required course work selected from the following list:

- ME 1800 Material Selection and Manufacturing Processes
- ME 2820 Materials Processing
- ME 3820 Computer-Aided Manufacturing
- ES 3011 Control Engineering I

II. **2/3 unit** of electives, selected from the following list of courses:

- ____ any of the courses above, in I., can count if the other three are completed.
- CS 4032 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 4530 Computational Methods in Mechanical Engineering
- ME 4815 Industrial Robotics
- ME 4821 Chemistry, Properties and Processing of Plastic
- MG/IE 3400 Production System Design
- MG/IE 3420 Quality Planning, Design and Control
- MFE 510 Control and Monitoring of Manufacturing Processes
- MFE 511 Application of Industrial Robotics
- MFE 520 Design and Analysis of Manufacturing Processes
- MFE 530 Computer Integrated Manufacturing
- MFE 540 Design for Manufacturability

III. **1/3 unit** of capstone experience:

- ME 4815 Industrial Robotics
- MFE xxxx Independent Study Project (this must be approved by the MFE minor program committee)

MFE 510 Control and Monitoring of Manufacturing Processes
MFE 511 Application of Industrial Robotics
MFE 520 Design and Analysis of Manufacturing processes
MFE 530 Computer Integrated Manufacturing
MFE 540 Design for Manufacturability

MATERIALS ENGINEERING

Courses and programs of study in materials engineering are included in the Mechanical Engineering Department (page 144). For advisory information, consult that section of the Undergraduate Catalog or members of the materials section of Mechanical Engineering.

MINOR IN MATERIALS

Material properties, material processing issues, or material costs are the limiting factor in the design or performance of almost all systems around us. Engineers, scientists, and managers in all technological sectors often must make material selection decisions based on a variety of considerations, including properties, performance, environmental impact, and cost. A Minor in Materials, feasible within a 15 unit program of study, will benefit students who wish to enhance their disciplinary major with an additional degree designation in the area of materials.

REQUIREMENTS FOR THE MATERIALS MINOR:
The minor requires the completion of 2 units of work[a] as described below:

1. ES 2001 Introduction to Material Science (1/3 unit)

2. 1 1/3 units of electives, selected from the following list of courses[b,c]:

CE 3026 Materials of Construction
CH 3410 Principles of Inorganic Chemistry
CH 2310 Organic Chemistry I
CH 2320 Organic Chemistry II
CH 2330 Organic Chemistry III
CH 4330 Organic Synthesis
CH 4550 Polymer Chemistry
CM 3601 Chemical Materials Engineering
EE 3901 Semiconductor Devices
ME 2820 Materials Processing
ME 3023 Mechanical Behavior and Modeling Properties of Engineering Materials
ME 3811 Microstructure Analysis and Control
ME 3825 Mechanical Metallurgy Laboratory
ME 4813 Ceramics
ME/BE 4814 Biomaterials
ME 4816 Materials Optimization for Engineers
ME 4821 Chemistry, Properties, and Processing of Plastics
ME 4822 Solidification Processes
ME 4832 Corrosion and Corrosion Control
ME 4840 Physical Metallurgy
ME 4850 Solid State Thermodynamics
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; CM 508, Catalysis and Surface Science of Materials; CM 510, Particulate Systems; CM 543, Molecular Sieves; CM 551, Structure and Properties of Polymeric Materials; CH 555, Advanced Topics/Polymer Chemistry and Advanced Topics/Nanotechnology.

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 4816 and ME 4822. 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 pages 26-27 of the Undergraduate Catalog.)

b. Undergraduates in any major who are considering graduate study in Materials Science and Engineering are advised to include ME 3023, ME 3811, ME 4840, and ME 4850 among their electives.

c. 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.

d. 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.

e. 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, CM, 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.

f. 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).

PERMISSIBLE MAJOR-MINOR COMBINATIONS
The Materials Minor is available to students of all majors. Students can earn *either* a Materials Minor designation *or* a Materials Concentration, not both.

MATHEMATICAL SCIENCES

H. F. WALKER, HEAD; W. FARR. ASSOCIATE HEAD
PROFESSORS: P. R. Christopher, P. W. Davis, M. Humi, K. A. Lurie, R. Y. Lui, J. D. Petruccelli, D. Tang, B. Vernescu, H. F. Walker
ASSOCIATE PROFESSORS: W. Farr, J. D. Fehribach, A. C. Heinricher, W. J. Martin, B. Nandram, B. Servatius, D. Vermes
ASSISTANT PROFESSORS: B. Doytchinov, C. Larsen, C. Morales, M. Sarkis, S. Weekes, J. Wilbur
VISITING FACULTY: G. Dalakouras, J.-H. Kimn, D. Pasca, D. Shon, A. Swift
ACADEMIC STAFF: J. Goulet, A. Wiedie

INTRODUCTION
What is the best way to route data through a computer network? How can the safety and efficacy of a new AIDS drug be established? Is there a way to combine different materials to form a composite with maximum strength for a given weight? How much should be charged for the option to buy a stock at a certain price in one year's time? How does one put a price tag on the risk presented by a 17-year old male driver? These are just some of the exciting challenges encountered by professionals in the mathematical sciences.

Study in the mathematical sciences requires hard work and discipline to attain the clarity, precision, logic, and economy of thought that recruiters from business, industry and academia value so highly in our graduates. And the rewards are substantial: mathematical science careers such as actuary, statistician and mathematician consistently rank at the top of lists of the most desirable professions. If what we've said so far interests you, read on to learn more about what mathematical scientists do, and particularly about how our programs-Mathematical Sciences and Actuarial Mathematics-can prepare you for a challenging and rewarding career.

PROGRAM IN MATHEMATICAL SCIENCES

Study in the mathematical sciences offers a broad spectrum of opportunities to the prospective major. While filled with open problems and subject to intense research in well-established areas, the mathematical sciences are constantly undergoing renewal as new questions and challenges arise in applications. Indeed, whole new areas of mathematical sciences are continually being born and existing areas are reinvigorated as surprising connections are discovered to the physical, biological, and social sciences, to computer science, and to engineering, business, industry, and finance. Not surprisingly, many of our majors are double majors who seek to apply mathematics to problems in their other fields. Such students are trained in the modeling, analysis, and computation necessary for solving problems in their other fields of interest.

Career opportunities for majors are many and varied. Recent graduates have embarked on careers in business and industry (e.g., Microsoft Corporation, Raytheon Company, Polaroid Corporation, MITRE Corporation, Fidelity Investments, Aetna Insurance, and Sun Life Financial) or have entered graduate school (e.g., Purdue University, University of California at Berkeley, Harvard University, Stanford University, Northwestern University, WPI) in such diverse disciplines as mathematics, statistics, law, management, physics, nuclear engineering, civil engineering, and education. More on career and employment opportunities can be found at the web sites of the Mathematical Association of America http://www.maa.org/students/career.html, or the American Statistical Association http://www.amstat.org/careers/index.html.

PROJECTS/INDEPENDENT STUDIES
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.

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 these cases, students will want to take special care to plan their programs carefully with their advisors so that sufficient backgrounds are obtained by the time the students begin their MQPs.

Many MQPs involve the solution of real-world problems proposed by industrial sponsors. Details can be found at http://www.wpi.edu/~cims.

A current listing of specific available projects with their descriptions is available at the department office, and at http://www.wpi.edu/Academics/Projects/available.html.

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. Some independent study areas and faculty advisors are listed below. In what follows, you will find for each MQP area:

- A brief description of the area including the kinds of challenges likely to be encountered by MQP students and mathematical scientists working there.
- Courses of interest.
- MQP and independent study topics and advisors.
- Examples of recent MQPs.

ALGEBRAIC AND DISCRETE MATHEMATICS

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

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

Courses of Interest

MA 2271 Graph Theory
MA 2273 Combinatorics
MA 3231 Linear Programming
MA 3233 Discrete Optimization
MA 3823 Group Theory
MA 3825 Rings and Fields
MA 4891 Topics in Mathematics (when appropriate)
CS 2005 Data Structures and Programming Techniques
CS 4120 Analysis of Algorithms
CS 4123 Theory of Computation

MQP AND INDEPENDENT STUDY TOPICS AND ADVISORS

Topic Area	Faculty Advisor(s)
Coding Theory and Cryptography	W. J. Martin, B. Servatius
Combinatorics	P. R. Christopher, W. J. Martin, B. Servatius
Discrete Optimization	W. J. Martin, B. Servatius
Finite Fields	W. J. Martin, B. Servatius
Graph Theory and Applications	P. R. Christopher, B. Servatius
Group Theory	P. R. Christopher, B. Servatius
Linear Algebra	P. R. Christopher, W. J. Martin, B. Servatius
Number Theory	W. J. Martin, B. Servatius

Some Recent Algebraic and Discrete Mathematics MQPs:

Properties of the Star-Chromatic Number
Student: Peter Minear
Advisor: P. R. Christopher

Given a graph (or "network") and a star with k points, can you assign a point of the star to each node of the graph so that no two adjacent nodes are assigned to points that are too close together? This is the idea of the star-chromatic number of a graph. This recent project examined the star-chromatic number, a recently proposed parameter in graph theory. We explored the relationship between this parameter and the classical, well-studied chromatic number. Also, we reviewed another parameter, the game-chromatic number.

Molecular Computation and Graph Theory
Students: Nathan Gibson, Angela Lusignan
Advisor: B. Servatius

Will the computers of the future incorporate DNA to quickly solve complex combinatorial problems? This interdisciplinary project consisting of graph theory, biology and computer science explored the capability of using DNA Computing to solve the existence of a directed Hamiltonian path. A mathematical model of the problem was designed to analyze the pre-conditioning of digraphs. Additionally, optimization techniques were developed in order to apply biological operations to digraphs efficiently. Results were obtained from each discipline to assess the viability of Molecular Computation.

COMPUTATIONAL AND APPLIED ANALYSIS

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

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

With the increase in computational power, many models previously too complicated to be solvable, can now be solved numerically. It is, therefore, recommended that students acquire enough computer proficiency to take advantage of this. Computational skill is growing in importance and should be a part of every applied mathematician's training. Students may learn these skills through various numerical analysis courses offered by the department. An MQP in this area will generally involve the modeling of a real-life problem, analyzing it, and solving it numerically.

Courses of Interest

MA 2251	Vector and Tensor Calculus for Engineers
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

MQP AND INDEPENDENT STUDY TOPICS AND ADVISORS

Topic Area	Faculty Advisor(s)
Calculus of Variations	C. Larsen, K. Lurie, B. Vernescu, M. Sarkis
Chemical Reaction Models	P. W. Davis, W. Farr
Composite Materials	C. Larsen, K. Lurie, B. Vernescu
Fluid Mechanics	M. Humi, D. Tang, S. Weekes
Mathematical Biology	R. Lui, D. Tang
Mathematical Physics	M. Humi, C. Larsen
Numerical Methods for Differential Equations/ Scientific Computation	W. Farr, J. D. Fehribach, M. Humi, M. Sarkis, D. Tang, H. Walker, S. Weekes
Optimal Control/Stochastic Control	A. C. Heinricher, D. Vermes

Some Recent Computational and Applied Analysis MQPs:

Control of Simultaneous Motion in Shoulder Prostheses
Students: Colleen Fox, Nicole Shivitz, Jason Wening
Advisors: P. W. Davis (MA), F. J. Looft (EE)

When designing a prosthetic arm, a key issue is the simultaneous control of motions in different joints. This project established design parameters of the control unit and predicted the forces that would act on the arm as it underwent different motions. A motion control system was then built, proving that digital signal processing can be used with analog technology to control the simultaneous motions and counteract the predicted inertial forces.

Math Modeling in Metal Processing
Students: Forest Lee-Elkin, William Montbleau, Stanislav Oks
Advisor: B. M. Vernescu
Sponsor: Morgan Construction Company

The project focused on the wear of a mechanism called a Laying Pipe, which coils steel rod in rolling mills. A mathematical model for the mechanism's wear was developed through a system of differential equations and was shown to closely match measured data. To improve the wear distribution, the optimal shape was numerically solved using mathematical techniques for minimization (the calculus of variations).

OPERATIONS RESEARCH

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

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

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

Courses of Interest

MA 2271	Graph Theory
MA 2273	Combinatorics
MA 3231	Linear Programming
MA 3233	Discrete Optimization
MA 3627	Applied Statistics III
MA 3631	Mathematical Statistics
MA 4235	Mathematical Optimization
MA 4237	Probabilistic Methods in Operations Research
MA 4631	Probability and Mathematical Statistics I
MA 4632	Probability and Mathematical Statistics II
MG 2500	Management Science I: Deterministic Decision Models
MG 3501	Management Science II: Risk Analysis
MG 3760	Simulation Modeling and Analysis

MQP AND INDEPENDENT STUDY TOPICS AND ADVISORS

Topic Area	Faculty Advisor(s)
Control Theory	K. Lurie, A. C. Heinricher
Stochastic Controls	D. Vermes, A. C. Heinricher
Stochastic Differential Equations	B. Doytchinov, A. C. Heinricher, D. Vermes

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 ap-

MATHEMATICAL SCIENCES MAJOR PROGRAM CHART

UNIVERSITY REQUIREMENTS	
Minimum Academic Credit	15 Units
Residency	8 Units
Sufficiency	2 Units
Interactive Qualifying Project	1 Unit
Major Qualifying Project	1 Unit
Social Science	2/3 Unit
Physical Education	1/3 Unit

FOUNDATION COURSES

INTRODUCTORY COURSES	TRANSITION COURSES (1 Unit Required)	CORE COURSES (4/3 Unit Required)
MA 1021-1024 or MA 1031-1034	MA 2073	Both MA 3831 and MA 3832
MA 2051	MA 2271*	One of MA 3257 or MA 3457
MA 2071	MA 2273*	One of MA 3823* or MA 3825*
MA 2201	MA 2431	
MA 2251	MA 2631	
MA 2611		

OTHER MA COURSES TO ATTAIN TOTAL OF 6 UNITS:

ACTUARIAL MATH	ANALYSIS	ALGEBRA	DISCRETE MATH	COMPUTA-TIONAL MATH	OPERATIONS RESEARCH	STATISTICS/ PROBABILITY
MA 3211	MA 2431	MA 2073	MA 2271*	MA 3257	MA 3231	MA 2612
MA 3212	MA 3471*	MA 3823*	MA 2273*	MA 3457	MA 3233*	MA 2621
MA 4213*	MA 3475*	MA 3825*	MA 3233*	MA 4411*	MA 4235*	MA 2631
MA 4214*	MA 4291				MA 4237*	MA 3627*
	MA 4451					MA 3631
	MA 4473*					MA 4214*
						MA 4631
						MA 4632
						MA 4658

OTHER REQUIREMENTS	
Computer Science Courses	2/3 Unit

* Category II courses, offered in alternating years.

plication 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 B.S. degree. More information about careers in statistics can be found at the American Statistical Association's web site http://www.amstat.org/profession/index.html .

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

MQP AND INDEPENDENT STUDY TOPICS AND ADVISORS

Topic Area	Faculty Advisor(s)
Applied Probability	A. C. Heinricher
Bayesian Statistics	B. Nandram
Biostatistics	
Categorical Data Analysis	
Industrial Applications	J. D. Petruccelli
Statistical Computation	
Stochastic Models	B. Nandram, J. D. Petruccelli
Survey Sampling Theory	B. Nandram
Time Series	J. D. Petruccelli

Some Recent Probability and Statistics MQPs:

Assessing Two Models to Map Colon Cancer Rates
Student: Brian Burwick
Advisor: B. Nandram

Previous work by the advisor used several models and three measures to study cancer and chronic obstructive pulmonary disease, and showed that one of the models is surprisingly better than another one. The goal of this project was to investigate how well these models perform for other causes of death, and sparser data sets. For colon cancer, the three measures were applied, and then a fourth measure was developed to compare the models. The project found that one model is still preferable to the other.

Statistical Consulting
Student: Jayson Wilbur
Advisor: J. D. Petruccelli
Sponsor: Bose Corporation

During a three month period, Jayson Wilbur served as a statistical consultant to the manufacturing and R&D divisions of Bose Corporation, a leading manufacturer of audio products. There he provided statistical expertise on four projects. The statistical methods he used included experimental design, data collection, analysis of variance, analysis of covariance, pairwise comparisons of proportions, aliasing structures, confounding patterns, testing for significance and non-parametric methods of analysis.

Program Distribution Requirements for the Mathematical Sciences Major

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

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

NOTES:

1. Must include MA 3831-3832, or their equivalents, at least one of MA 3257, MA 3457, or equivalent, and at least one of MA 3823, MA 3825, or equivalent.
2. Must include at least three of the following: MA 2073, MA 2271, MA 2273, MA 2431, MA 2631, or their equivalents.
3. At least 7/3 units must consist of MA courses at the 3000 level or above.
4. May not include both MA 2631 and MA 2621.
5. May not include both CS 3043 and CS 2022.

PROGRAM IN ACTUARIAL MATHEMATICS

An actuary is a business professional who uses mathematical skills to define, analyze, and solve financial and social problems. Preparation for a career as an actuary requires mathematical aptitude, but actuarial work involves a practical type of mathematical ability mixed with business skills. An actuary deals with real-life problems rather than theoretical ones, must be curious, have sound judgment, and be able to think logically and creatively. The goal of the program in actuarial mathematics is to prepare students for positions in life and health insurance companies, property and casualty insurance companies, consulting firms, or state or federal government agencies.

The most widely accepted standard of professional qualification to practice as an actuary in the United States is a Fellowship in either the Society of Actuaries (SoA) or the Casualty Actuarial Society (CAS). Each organization administers a series of examinations leading to Fellowship. The first few in this series are mathematical in nature covering topics in calculus and linear algebra, probability, mathematical and applied statistics. Students interested in the actuarial mathematics program should read the latest SoA Associateship Catalog for more information. This catalog may be obtained from the Department of Mathematical Sciences, or at http://www.soa.org.

The actuarial mathematics program at WPI provides the first steps in preparing for these examinations and an introduction to fundamentals in business and economics. Students with mathematical aptitude should be able to pass the first two SoA examinations before graduation.

After graduation, most actuarial training is through self-study combined with on-the-job experience. Many employers rotate their actuarial trainees through various assignments exposing them to different aspects of business operations. In addition, companies frequently maintain actuarial libraries, sponsor group study sessions, and give trainees study time during work hours.

Brief descriptions of the project opportunities, distribution requirements, and the actuarial examinations are given below.

PROJECTS/INDEPENDENT STUDIES

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. 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.

Students should select MQP and independent study topics which are related to their areas of preparation and interest. Some project and independent study areas are given below. In addition, a current listing of specific available projects with their descriptions is available at the department office, and at http://www.wpi.edu/Academics/Projects/available.html.

MQP AND INDEPENDENT STUDY TOPICS AND ADVISORS

Topic Area	Faculty Advisor(s)
Actuarial Models (Stochastic and Deterministic)	A. Wiedie
Asset/Liability Management	D. Vermes
Auto Insurance Cession Strategies	A. Heinricher
Interest Rate Modeling	D. Vermes
Mathematical Finance	R. Lui
Pricing Insurance and Annuity Contracts	A. Wiedie
Risk Classification	A. Heinricher
Survival Models	A. Wiedie

Some Recent Actuarial Mathematics MQPs:

Development of a Test Algorithm for Cession Strategies

Students: Kristen Magnifico, Jeremey Olszewski, Daniele Recore
Advisor: A. C. Heinricher
Sponsor: Premier Insurance Company

New methods for computing and predicting the net gain or loss for a certain cession strategy were explored for the Premier Insurance Company of Massachusetts. (Insurance companies can cede high-risk policies to Commonwealth Auto Reinsurance.) Various one and two-stage strategies were created using different variables. This tool can now be used by Premier to test future strategies. It can be helpful in investigating the sensitivity of the strategies to fluctuation in certain parameters, including CAR's deficit, that help determine Premier's gain or loss.

Pricing Guaranteed MV Life Insurance Policies

Students: Aaron Korthas, Shelby Woods
Advisor: A. Wiedie
Sponsor: John Hancock Life Insurance

By simulating hypothetical Medallion Variable Life Insurance policies, appropriate premiums are determined to guarantee a death benefit for various lengths of time under various investment scenarios. With these premiums there is an estimated high probability of having an adequate account balance by the end of the guarantee periods. As with any guarantee, John Hancock will lose money on policies that fail. Additional fees are calculated to offset the expected losses of failed policies.

Program Distribution Requirements for the Actuarial Mathematics Major

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

Requirements	Minimum Units
1. Mathematics (including MQP) (See notes 1-6).	7
2. Management (See note 7).	4/3
3. Additional courses or independent studies (except MS, PE courses, and other degree requirements) from any area (See note 8).	5/3

NOTES:

1. Must include MA 3831and MA 3832, or their equivalents, at least one of MA 3257, MA 3457, or equivalent, and at least one of MA 3631, MA 4632, or equivalent.
2. Must include two of the following: MA 2073, MA 2271, MA 2273, MA 2431, MA 2631, or their equivalents.
3. Must include three of the following: MA 3211, MA 3212, MA 4213, MA 4214, or their equivalents.
4. May not include independent studies directed toward Society of Actuaries exams.
5. May not include either MA 2201 or MA 2210.
6. May not include both MA 2631 and MA 2621.
7. Must include MG 2101 and MG 2200 or their equivalents.
8. Must include 2/3 units of computer science.

WPI COURSES AND THE SOCIETY OF ACTUARIES (SOA) EXAMINATIONS

The formulation of the distribution requirements for the program in actuarial mathematics was in large part motivated by the nature of the sequence of examinations that lead to Fellowship in the SoA or CAS. In particular, there are a number of WPI courses that cover fundamental topics that are included on the first few exams in this sequence.

ACTUARIAL MATHEMATICS MAJOR PROGRAM CHART

UNIVERSITY REQUIREMENTS	
Minimum Academic Credit	15 Units
Residency	8 Units
Sufficiency	2 Units
Interactive Qualifying Project	1 Unit
Major Qualifying Project	1 Unit
Social Science	2/3 Unit
Physical Education	1/3 Unit

FOUNDATION COURSES

INTRODUCTORY COURSES	TRANSITION COURSES (2/3 Unit Required)	CORE COURSES (4/3 Unit Required)	ACTUARIAL COURSES (1 Unit Required)
MA 1021-1024 or MA 1031-1034	MA 2073	Both MA 3831 and MA 3832	MA 3211
MA 2051	MA 2271*	One of MA 3257 or MA 3457	MA 3212
MA 2071	MA 2273*	One of MA 3631* or MA 4632*	MA 4213*
MA 2201	MA 2431		MA4214*
MA 2210	MA 2631		
MA 2251			
MA 2611			

OTHER MA COURSES TO ATTAIN TOTAL OF 6 UNITS:

ACTUARIAL MATH	ANALYSIS	ALGEBRA	DISCRETE MATH	COMPUTA-TIONAL MATH	OPERATIONS RESEARCH	STATISTICS/ PROBABILITY
MA 3211	MA 2431	MA 2073	MA 2271*	MA 3257	MA 3231	MA 2612
MA 3212	MA 3471*	MA 3823*	MA 2273*	MA 3457	MA 3233*	MA 2621
MA 4213*	MA 3475*	MA 3825*	MA 3233*	MA 4411*	MA 4235*	MA 2631
MA 4214*	MA 4291				MA 4237*	MA 3627*
	MA 4451					MA 3631
	MA 4473*					MA 4214*
						MA 4631
						MA 4632
						MA 4658

OTHER REQUIREMENTS

Computer Science (2/3 Unit Required)

Management (4/3 Unit Required)	
Required	Suggested
MG 2101	MG 1100
MG 2200	MG 2250*
	MG 2260
	MG 2300
	MG 2500
	MG 3501
	MG 3760

* Category II courses, offered in alternating years.

Society of Actuaries Examination	WPI Courses
1. Mathematical Foundations of Actuarial Science	MA 1021 to MA 1024, MA 2631
2. Interest Theory, Economics and Finance	MA 3211, SS 1110, SS 1120, MG 1100, MG 2200
3. Actuarial Models	MA 3212, MA 4213, MA 4214, MA 2431, MA 4237
4. Actuarial Modeling	In addition to topics in 3.: MA 2071, MA 2611, MA 2612, MA 3627

It must be emphasized that course work alone is not sufficient preparation for the examinations listed above; passage requires additional self-study. Several publications of the Society of Actuaries are available in the mathematics department office, and comprehensive information may be found at http://www.soa.org and http://www.casact.org. In addition, requests for information about the actuarial profession can be sent to the Society of Actuaries, 475 North Martingale Road, Suite 800, Schaumburg, IL 60173-2226.

STATISTICS MINOR

Statistical methods are widely used in science, engineering, business, and industry. The Statistics Minor is appropriate for all WPI students with interests in experimental design, data analysis, or statistical modeling. The minor is designed to enable a student to properly design studies and analyze the resulting data, and to evaluate statistical methods used in their field of study.

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. **Capstone Experience** The capstone experience usually consists of completion of MA 4658, Statistical Consulting. In this course, undergraduate students work with statistics faculty and graduate students to learn statistical practice and provide statistical advice to clients from the WPI community. Alternatively, students may arrange an independent study with one of the statistics faculty.

For information about the Statistics Minor, see any of the statistics faculty: Professors Joseph D. Petruccelli, Balgobin Nandram, Carlos Morales, Ann H. Wiedie, or Jason Wilbur.

MATHEMATICS MINOR

The Minor in Mathematics consists of successful completion of at least 2 units of academic activities in mathematical sciences satisfying the following requirements:

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 integrating capstone experience requires prior approval by the Mathematical Sciences Program Review Committee. The experience may be satisfied by certain 3000-level, 4000-level or graduate courses offered by the department (with instructor approval) or by a suitable independent study with a Mathematical Sciences faculty member. At the conclusion of the process, the student will fill out the Mathematics Minor Program Approval Form to be signed by the Capstone Experience instructor and the Program Review Committee.

   Students are encouraged to choose thematically-related courses toward their minor so as to gain in-depth knowledge in some sub field of mathematics. The course selection should be discussed in advance with a Mathematical Sciences Department faculty member. Here are some examples of 5/3 units of coursework for four thematically-related minors. Other options are available.

Applied Analysis	Computational Analysis	Differential Equations	Discrete Mathematics	Operations Research
MA 2051	MA 2051	MA 2051	MA 2201	MA 2071
MA 2071	MA 2071	MA 2251	MA 2271	MA 2073
MA 2431	MA 2073	MA 3471	MA 2273	MA 3231
MA 3831	MA 3257	MA 4411	MA 3233	MA 3233
MA 3832	MA 3457	MA 4473	MA 533	MA 4235 or MA 4237

MECHANICAL ENGINEERING

G. TRYGGVASON, HEAD

PROFESSORS: D. Apelian, I. Bar-On, R. R. Biederman, C. A. Brown, M. Dimentberg, W. W. Durgin, R. R. Hagglund, A. H. Hoffman, H. Johari, R. L. Norton, R. J. Pryputniewicz, J. J. Rencis, B. J. Savilonis, R. D. Sisson, Jr., J. M. Sullivan, Jr., G. Tryggvason

ASSOCIATE PROFESSORS: H. K. Ault, C. Demetry, N. Gatsonis, Z. Hou, M. M. Makhlouf, D. J. Olinger, M. W. Richman, Y. Rong, S. Shivkumar

ASSISTANT PROFESSORS: J. Blandino, M. Demetriou, M. Fofana, Y.-M. Moon

VISITING ASSISTANT PROFESSOR: E. C. Cobb

SAINT-GOBAIN PROFESSOR: C. A. Brown

EMERITUS PROFESSORS: J. M. Boyd, H. T. Grandin, W. A. Kistler, J. A. Mayer, Jr., K. E. Scott, D. N. Zwiep

MISSION STATEMENT

The Mechanical Engineering program at WPI is designed to develop graduates who can deal with real world situations that involve technological and humanistic/societal issues. Students develop literacy and competency in utilizing scientific and engineering methods for devising useful products in an economical way, while considering the impacts on society. The Mechanical Engineering program is in harmony with the WPI Plan philosophy of education, in which each student develops competence, confidence and the skill of self-learning.

EDUCATIONAL PROGRAM OBJECTIVES

The Mechanical Engineering Program seeks to have alumni who:

- are successful professionals because of their mastery of the fundamental engineering sciences, mechanical engineering, and the design process.
- are leaders in 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.

EDUCATIONAL OUTCOME

Graduating students should demonstrate the following at a level equivalent to an entry-level engineer or first year graduate student:

1. An understanding of the fundamental principles of conservation laws, constitutive relations, mechanics and materials science.
2. The ability to apply mathematics, science and engineering to thermofluid and mechanical systems.
3. The ability to design a system, component or process to meet design criteria.
4. The ability to design and conduct experiments and to analyze and interpret the resulting data.
5. The ability to use modern engineering tools for engineering design and analysis.
6. The ability to communicate effectively both verbally and in writing.
7. The ability to function within multidisciplinary teams.
8. The ability to function professionally and ethically.
9. An understanding of contemporary issues and the impact of engineering solutions in a global/societal context.
10. An appreciation for the skills to accomplish life-long learning.
11. Knowledge of chemistry and calculus-based physics with depth in at least one.
12. The ability to apply advanced mathematics through multivariate calculus and differential equations.
13. Familiarity with statistics and linear algebra.

INTRODUCTION

Mechanical engineering uses the basic laws of the physical sciences, life sciences, the social science, and the humanities in their quest to serve mankind.

Airplanes, automobiles, trains, space vehicles, earth-moving equipment, nuclear reactors, plasma generators, heart-lung machines, miniature bearings, machines and machine tools, sewing machines, and power lawn mowers are but a few examples of the products with which mechanical engineering is associated.

Compared with other fields of engineering, mechanical engineering is the broadest in application as well as the most basic. Mechanical engineers design products, supervise production, conduct research and development, and manage businesses or technical operations. In addition, mechanical engineering requires persons who can use the sciences to devise useful products in an economic manner while minimizing the loss of our natural resources.

Looking forward to this wide range of possible careers, mechanical engineering students should get a sound foundation in mathematics and science, plan a sequence of cultural and social studies, aim for a real understanding of the fundamentals of engineering, and achieve a proper balance between theory and application. A working knowledge of computers must be established through formal or informal learning processes. Inspection trips to industrial plants and cooperative education assignments are encouraged.

In this regard, the Mechanical Engineering Department offers extensive, modern, well-equipped facilities in the Higgins and Washburn Laboratories. These laboratories, covering the broad spectrum of mechanical engineering activities, are briefly described in the *Resources available to Undergraduate Students* section of this Catalog. They are widely used by the students enrolled in Mechanical Engineering and related programs.

MECHANICAL ENGINEERING PROGRAM CHART

STUDENTS EARNING A B.S. DEGREE IN MECHANICAL ENGINEERING MUST COMPLETE 15 UNITS OF STUDY, DISTRIBUTED AS FOLLOWS:

4 UNITS OF NON-TECHNICAL ACTIVITIES

2 UNITS H&A SUFFICIENCY	*See WPI Requirements*
1 UNIT INTERACTIVE QUALIFYING (IQP) PROJECT	*See WPI Requirements*
2/3 UNIT SOCIAL SCIENCE	*See WPI Requirements*
1/3 UNIT PHYSICAL EDUCATION	*See WPI Requirements*

1 UNIT FREE ELECTIVE

1 UNIT FREE ELECTIVE	*See Catalog*

4 UNITS OF MATHEMATICS AND BASIC SCIENCE

4/3 Units
Student Selected Courses from the General Category of Mathematics and/or Basic Science

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

MATHEMATICS
MA 1021 MA 1023
MA 1022 MA 1024
MA 2051

3/3 Units
One Chemistry and Two Physics, OR One Physics and Two Chemistry

SCIENCE
CH 1010 CH 1020
PH 1110 PH 1120

6 UNITS OF MECHANICAL ENGINEERING (Notes 1 & 2)

1 unit required	1 unit required	1 unit required	1 unit required	2 units required
MECHANICAL SYSTEMS	THERMOFLUID SYSTEMS	OTHER COURSES	MAJOR QUALIFYING PROJECT (MQP)	ELECTIVES
ES 2501 ES 2502 ES 2503	ES 3001 ES 3003 ES 3004	ES 2001 EE 3601 ME 3901		At least one unit must be chosen as ES or ME courses at the 4000-level.

The courses listed above can be replaced by other equivalent courses, with approval by the ME Program Committee.

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

OTHER ACTIVITIES					
Linear Algebra	Statistics	Mechanical System Design	Thermofluid System Design	Realization	Capstone Design
MA 2071 ME 3501 MA 2073 ME 4505 MA 4411 ME 4512 ME 3311 ME 4530 ME 3321 ME 4605	MA 2611 MA 2612 MA 2621 ME 3901	ME 3310 ME 4320 ME 3311 ME 4430 ME 3320 ME 4770 ME 3506 ME 4771 ME 4816 MQP (depending on topic)	ME 4429 ME 4430 ME 4770 ME 4771 MQP (depending on topic)	ES 3323 ME 1800 ME 2300 ME 3506 MQP (depending on topic)	ME 4320 ME 4429 ME 4430 ME 4770 ME 4816 MQP (depending on topic)

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

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 22), students wishing to receive the ABET-accredited degree designated "Mechanical Engineering" must satisfy certain additional distribution requirements. These requirements apply to 10 units of study in the areas of mathematics, basic science, and engineering science and design as follows:

Requirements	Minimum Units
1. Mathematics and Basic Science (Notes 1, 2, 3).	4
2. Engineering Science and Design (includes MQP) (Notes 3, 4, 5, 6, 7, 8, 9).	6

NOTES:

1. Must include a minimum of 5/3 units of mathematics, including differential and integral calculus and differential equations.
2. Must include a minimum of 1/3 unit in chemistry and 2/3 unit in physics, or 1/3 unit in physics and 2/3 unit in chemistry.
3. Must include an activity that involves basic matrix algebra and the solution of systems of linear equations, and an activity that involves data analysis and applied statistical methods.
4. Must include 1/3 unit in each of the following: electrical engineering, materials science, and mechanical engineering experimentation.
5. Must include at least one unit of ME courses at the 4000-level.
6. May include 1000 level courses only if designated ES or ME.
7. Must include two stems of coherent course and/or project offerings as noted below in a and b.
   a. A minimum of one unit of work in thermofluid systems that includes the topics of thermodynamics, fluid mechanics and heat transfer, plus an activity that integrates thermofluid design.
   b. A minimum of one unit of work in mechanical systems that includes the topics of statics, dynamics, and stress analysis, plus an activity that integrates mechanical design.
8. Must include an activity which realizes (constructs) a device or system.
9. Must include 1/3 unit of Capstone Design Experience.

Items 3, 5, 7a integration, 7b integration, 8, 9 may all be "multiple-counted."

Each Mechanical Engineering student must complete a Capstone Design experience requirement. This capstone design experience is partially or fully accomplished by completing a Major Qualifying Project which integrates the past course work and involves significant engineering design. At the time of registration for the MQP, the project advisor will determine whether the MQP will meet the Capstone Design requirement or not. If not, the advisor will identify an additional 1/3 unit of course work in the area of design (ME 4320, ME 4429, ME 4430, ME 4770, or ME 4816) to be taken in order to meet the ABET Capstone Design requirement.

FUNDAMENTALS IN THE MAJOR

The WPI philosophy of education emphasizes the development of competence in students' abilities in self-learning. In the context of the flexible WPI degree requirements and the breadth of the mechanical engineering profession, it is not possible—or beneficial—to specify a rigid educational pattern. Rather, each student, with advice, should develop a program that best meets personal and professional goals.

It is clear that the profession of mechanical engineering rests on a deep understanding of the concepts of science and mathematics. The distribution requirements establish the minimum framework for meeting the student's educational goals.

HUMANITIES/SOCIAL SCIENCES

It is difficult for mechanical engineers to design systems without being literate in the disciplines making up the social sciences, for the concerns of people and the flow of capital—economies—are central to technological development. The questions of values and mankind's cultural experiences as exemplified in the humanities are critical to the study of modern technology. More and more engineering students recognize the need for literacy in the *humanities and social sciences*, and the Humanities and Arts Sufficiency and Social Sciences degree requirements are designed to meet this need. Mechanical engineering students are urged to work closely with their Sufficiency and Social Studies advisors as well as their academic advisor in the Mechanical Engineering Department to develop a program which meets their needs.

DISCIPLINARY LITERACY

In addition to disciplinary literacy, the process of design and problem solving is best met by multidisciplinary, problem-oriented experiences. At WPI, *projects* and *independent studies* are best suited to this educational experience. It may be difficult to generalize as to whether the student should develop literacy in a particular area by course or project experiences. *Courses* are sometimes the optimum mode in developing a disciplinary background, while projects are often effective in multidisciplinary, problem-centered studies. Mechanical engineering students should design programs that take full advantage of *both* of these learning modes.

The academic program of the student should be designed to provide for a continuous development in the scientific and engineering areas, including *analysis*, *design*, and *experimental studies*. Students are urged to take the Fundamentals of Engineering Examination, the first step toward becoming a registered professional engineer (P.E.), at the earliest opportunity.

AREAS IN WHICH COMPETENCE SHOULD BE DEVELOPED

The academic program of mechanical engineering students typically progresses from mathematics and basic science in the earliest years, through the engineering sciences, and then to analysis, design and experimentation. An operational capability in the use of computers must be acquired early in students' programs, as well as an overall skill in graphic, oral, and written communications. *Humanities and arts* and *social science* studies are essential in the program. When applicable, advanced placement from high schools will be given appropriate credit and noted on the WPI transcript.

MECHANICAL ENGINEERING DEPARTMENT CONCENTRATIONS

AEROSPACE ENGINEERING (GATSONIS)

Students are provided with ample opportunity to develop technical competence in low- and high-speed aerodynamics, propulsion systems, structures, and aerospace systems design. Experimental facilities available for course and projects in aerospace engineering include several wind tunnels, vacuum chambers, and controls instrumentation. Modern computational laboratories are also available.

Typical MQPs include: the design, construction, and testing of remotely piloted aircraft and micro aerial vehicles; aerodynamics; flow and structural control; gas dynamics; combustion; electric propulsion; micropropulsion.

Aerospace
2 Required
- ME 2713 Astronautics
- ME 3711 Aerodynamics

Select 4
- ME 3410 Flow of Compressible Fluids
- ME 3715 Rocket and Spacecraft Propulsion **or**
  - ME 3716 Air Breathing Propulsion
- ME 4605 Computational Fluid Mechanics
- ME 4712 Supersonic Aerodynamics
- ME 4715 Aerospace Structures
- ME 4724 High Speed Flow
- ME 4770 Aircraft Design **or**
  - ME 4771 Spacecraft and Mission Design

*Plus Aerospace MQP

BIOMECHANICAL (HOFFMAN)

Students blend biology and biotechnology coursework with continuum mechanics, biomechanics, biofluids, and biomedical materials to support their individual interest. MQPs are usually developed jointly with off-campus medical facilities, including the University of Massachusetts Medical Center.

Typically MQP topics include: soft tissue mechanics, flow in constricted blood vessels, joint kinematics, prosthetic devices, sports biomechanics, biomaterials, tissue engineering and rehabilitation.

Biomechanical
Two (2) Biology and Biotechnology (BB) Courses
Select 4
- ME 3501 Elementary Continuum Mechanics
- ME 3506 Rehabilitation Engineering
- ME 4504 Biomechanics
- ME 4606 Biofluids
- ME 4814 Biomedical Materials
- Any BE course at the 3000-level or higher

* Plus Biomechanical-related MQP

ENGINEERING MECHANICS (RENCIS)

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 3023	Mech. Behavior & Modeling Properties of Eng'g Mat'ls
ME 3501	Elementary Continuum Mechanics
ME 3502	Advanced Stress Analysis
ME 3506	Rehabilitation Engineering
ME 3602	Intermediate Fluid Dynamics
ME/BE 4504	Biomechanics
ME 4505	Advanced Dynamics
ME 4506	Mechanical Vibrations
ME 4512	Introduction to the Finite Element Method
ME 4530	Computational Methods in Mechanical Engineering

* Plus Engineering Mechanics MQP

MECHANICAL DESIGN (NORTON)

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

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

Mechanical Design
2 Required
- ME 3310 Kinematics of Mechanisms
- ME 3320 Design of Machine Elements

Select 4
- ES 1310 Engineering Design Graphics
- ES 3323 Introduction to CAD
- ME 2300 Introduction to Engineering Design
- ME 3311 Dynamics of Mechanisms and Machines
- ME 3321 Dynamic Modeling
- ME 3506 Rehabilitation Engineering
- ME 4320 Advanced Engineering Design
- ME 4815 Industrial Robotics
- ME 4816 Materials Optimization for Engineers

* Plus Mechanical Design MQP

MECHANICAL ENGINEERING DEPARTMENT CONCENTRATIONS

MANUFACTURING (C. A. BROWN)

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, computer-controlled machining, surface metrology, fixturing, machine dynamics, grinding, precision engineering, prototype manufacturing.

See also the Manufacturing Engineering degree program.

Manufacturing

Select 2
- ME 1800 Materials Selection and Manufacturing Processes
- ME 2820 Materials Processing
- ME 3023 Mechanical Behavior and Modeling Properties of Engineering Materials
- ME 4816 Materials Optimization for Engineers
- ME 4821 Chemistry, Properties, and Processing of Plastics
- ME 4822 Solidification Processing

Select 2
- ES 3011 Control Engineering I
- ME 3820 Computer-Aided Manufacturing
- ME 4815 Industrial Robotics

Select 2
- MG 2850 Engineering Economics
- MG 3400 Production System Design
- MG 3401 Production Planning and Control

* Plus Manufacturing MQP

MATERIALS SCIENCE AND ENGINEERING (SISSON)

Students interested in a strong materials science and engineering component can elect course and project activities in metals, ceramics, polymers, and composite materials with laboratory and project experience using facilities in Stoddard Laboratories.

Typical MQP topics include: X-ray diffraction, electron microscopy, computer modeling, mechanical testing and deformation mapping, plastic deformation, ceramic processing, friction, wear, corrosion, and materials processing.

Another option in the materials program is a Minor in Materials, which is described under Materials Engineering in this catalog.

Materials Science

Select 2
- ME 2820 Materials Processing
- ME 4816 Materials Optimization for Engineers
- ME 4822 Solidification Processing

Select 2
- ME 3023 Mech. Behavior and Modeling Properties of Eng'g Mat'ls
- ME 3811 Structure of Materials
- ME 4813 Ceramics
- ME 4814 Biomedical Materials
- ME 4821 Chemistry, Properties, and Processing of Plastics
- ME 4832 Corrosion and Corrosion Control

Select 2
- ME 4840 Physical Metallurgy
- ME 4850 Solid State Thermodynamics
- Any 500-level MTE course

* Plus Materials Science MQP

THERMAL-FLUID ENGINEERING (OLINGER)

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

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

Thermal-Fluids

Select 6
- ME 3410 Compressible Flow
- ME 3602 Intermediate Fluid Mechanics
- ME 3711 Aerodynamics I
- ME 3716 Air Breathing Propulsion
- ME 4412 Introduction to Combustion
- ME 4429 Thermodynamic Applications and Design
- ME 4605 Computational Fluid Mechanics
- ME 4606 Biofluids
- ME 4724 High Speed Flow

* Plus Thermal-Fluids MQP

Notes:
1. A Concentration area requires a 1 unit of MQP in that area.
2. After consultation with their academic advisor, students may petition the M.E. Dept. Curriculum Committee for approval of a Concentration plan at any time, preferably prior to the middle of their Junior Year.

MATHEMATICS AND BASIC SCIENCES

It is essential that mechanical engineering students establish a solid foundation in *mathematics*, the fundamental language of engineers. It is recommended that mechanical engineering students develop competence, as a minimum, in calculus and differential equations through such courses as: MA 1021, MA 1022, MA 1023, MA 1024, MA 2051. Additional courses are desirable and should be selected in consultation with the student's academic advisor as preparation for advanced-level course and project work.

An adequate background in the *basic sciences* is mandatory for mechanical engineering students and typically includes physics, chemistry, and other sciences. Programs should be planned so that topics related to mechanics, energy, heat, light, sound, optics, and electricity are covered in preparation for the material to be studied in the engineering sciences. Students, in consultation with their advisors, are urged to include in their programs courses from the following list which support their technical interest: PH 1110, PH 1120, PH 1130, CH 1010, CH 1020, CH 1030, BB 1001, BB 2002, GE 2341, GE 3050. Mathematics and basic sciences must include a minimum of four units, include both chemistry and physics with a minimum of two courses in either, and include differential and integral calculus and differential equations.

ENGINEERING SCIENCE AND DESIGN

For mechanical engineering students, the *engineering science and design* will normally require the equivalent of a year and a half of full-time study. In the engineering sciences, graphics; mechanics of solids, including stress analysis and dynamics; thermodynamics; fluid and continuum mechanics; materials science; and materials processing provide a background for the higher-level experiences. Students must also develop competence in closely-related engineering and science areas, such as electrical engineering, control engineering, computer science, and heat and mass transfer. A partial listing of engineering science courses of direct interest to the mechanical engineering student follows: ES 1310, ES 2001, ES 2501, ES 2503, ES 3001, ES 3003, ES 3004, ES 3011, ES 3323, ME 3501, ES 2502, ME 3502, ME 3505, EE 2011, EE 2022, EE 3601, and ES 2011.

With mastery of the basic and engineering sciences, mechanical engineering students are in a strong position to utilize the tools of their profession for the gaining of new knowledge and the solution of significant real-world problems, often termed "design." Their MQP and IQP enable them to specialize in a given area of mechanical engineering in an interdisciplinary setting.

Engineering design is the decision-making experience of an engineer in which the combination of the basic sciences, engineering sciences and mathematics is applied, with judgment, to use resources economically to meet stated objectives. The development of literacy and skill in design may include the establishment of objectives, criteria, synthesis, analysis, construction, experimentation, evaluation, and communication. Students should consult their advisors in selecting appropriate courses, projects and independent studies to meet their design requirements. Programs include the equivalent of at least one-half year of a design experience and often involve courses such as ME 2300, ME 3310, ME 3311, ME 3320, ME 3321, ME 4320, and ES 3323 plus the Major and Interactive Qualifying Projects along with independent study. Advanced design courses are available if a student decides to do in-depth study in this area. A minimum of six units of engineering science/design is required, and subdivided between engineering science and design on a 2:1 basis.

The one unit energy stem requirement is normally satisfied by taking courses such as ES 3001, ES 3003, and ES 3004. The one unit mechanical systems stem requirement is normally satisfied by taking courses such as ES 2501, ES 2502, and ES 2503.

Field trips and professional society activities are encouraged as they enhance overall professional perspectives.

MECHANICAL ENGINEERING DEPARTMENT CONCENTRATIONS

After developing competence in the basic engineering and science areas, mechanical engineering students are encouraged to select courses and projects in line with their personal and professional interests.

For those students having broad technical interests, and who wish to select wide-ranging upper-level courses *(see the Mechanical Engineering Program Chart)* and suitable MQP, early and continuing consultation with their academic advisors is encouraged to ensure that suitable preliminary work is completed on an appropriate schedule.

For those students that have an interest in pursuing upper-level activities within a narrow area of mechanical engineering, the Department offers seven specialty areas in which a "Concentration" may be earned. Each requires completion of six courses specified by that area, plus an MQP in that area. A brief description of each Concentration area, the name of a faculty member well versed in all phases of that area, and the particular course options and requirements are noted in the *Mechanical Engineering Concentrations chart.*

Students should note that they may utilize graduate courses if they are appropriate. The academic advisor must approve the course in advance. Integrated undergraduate-graduate programs are encouraged.

ENHANCED PROGRAMS

BS-MS 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 236.

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.

MECHANICAL ENGINEERING COURSES

		Category
Aerospace Engineering		
ME 2713	Astronautics	I
ME 3410	Flow of Compressible Fluids	I
ME 3711	Aerodynamics	I
ME 3715	Rocket and Spacecraft Propulsion or	II (03-04)
ME 3716	Air Breathing Propulsion	II (04-05)
ME 4712	Supersonic Aerodynamics	II (04-05)
ME 4715	Aerospace Structures	I
ME 4724	High Speed Flow	I
ME 4770	Aircraft Design or	I
ME 4771	Spacecraft and Mission Design	II (04-05)
Engineering Experimentation		
ME 3901	Engineering Experimentation	I
Engineering Mechanics		
ES 2501	Introduction to Static Systems	I
ES 2502	Stress Analysis	I
ES 2503	Introduction to Dynamic Systems	I
ME 1520	Mechanics of Alpine Skiing	
ME 3023	Mechanical Behavior and Modelling Properties of Engineering Materials	I
ME 3501	Elementary Continuum Mechanics	I
ME 3502	Advanced Mechanics of Materials	I
ME 3506	Rehabilitation Engineering	I
ME/BE 4504	Biomechanics	II (03-04)
ME 4505	Advanced Dynamics	II
ME 4506	Mechanical Vibrations	I
ME 4512	Introduction to the Finite Element Method	I
ME 4530	Computational Methods in Mechanical Engineering	II
ME 4922	Theory and Practice of Laser Instrumentation	I
Manufacturing Engineering		
ME 1800	Material Selection and Manufacturing Processes	I
ME 2820	Materials Processing	I
ME 3820	Computer-Aided Manufacturing	I
ME 4815	Industrial Robotics	I
Materials Science and Engineering		
ES 2001	Introduction to Material Science	I
ME 3023	Mechanical Behavior and Modeling Properties of Engineering Materials	I
ME 3811	Microstructure Analysis and Control	I
ME 4813	Ceramics	II
ME/BE 4814	Biomaterials	I
ME 4816	Materials Optimization for Engineers	II (03-04)
ME 4821	Chemistry, Properties and Processing of Plastics	II
ME 4822	Solidification Process	II (04-05)
ME 4832	Corrosion and Corrosion Control	II (04-05)
ME 4840	Physical Metallurgy	I
ME 4850	Solid State Thermodynamics	I
Mechanical Design		
ES 1310	Engineering Design Graphics	I
ES 3323	Introduction to CAD	I
ME 2300	Introduction to Engineering Design	I
ME 3310	Kinematics of Mechanisms	I
ME 3311	Dynamics of Mechanisms and Machines	I
ME 3320	Design of Machine Elements	I
ME 3321	Dynamic Modeling	I
ME 4320	Advanced Engineering Design	I
Thermal/Fluid Engineering		
ES 3000	Classical Thermodynamics	I
ES 3001	Introduction to Thermodynamics	I
ES 3003	Heat Transfer	I
ES 3004	Fluid Mechanics	I
ME 3410	Compressible Flow	I
ME 3422	Environmental Issues and Analysis	II (03-04)
ME 3601	Principles of Mechanical Engineering	I
ME 3602	Intermediate Fluid Dynamics	I
ME 4412	Introduction to Combustion	II (04-05)
ME 4429	Thermofluid Applications and Design	I
ME 4604	Fluid Mechanics of Machines	II (03-04)
ME 4605	Computational Fluid Mechanics	I
ME/BE 4606	Biofluids	II (04-05)
Special Topics		
ME 4010	Seminar	I
IS 4 ME	Special Topics	I

Independent study topics in mechanical engineering may be arranged. Consult faculty in the specific technical area for details.

MILITARY SCIENCE

LTC RICHARD B. O'CONNOR, HEAD
ASSISTANT PROFESSORS: MAJ P. Martin, MAJ Harold Rider, MSG John Veals, Jr., SFC John McPhee

INTRODUCTION

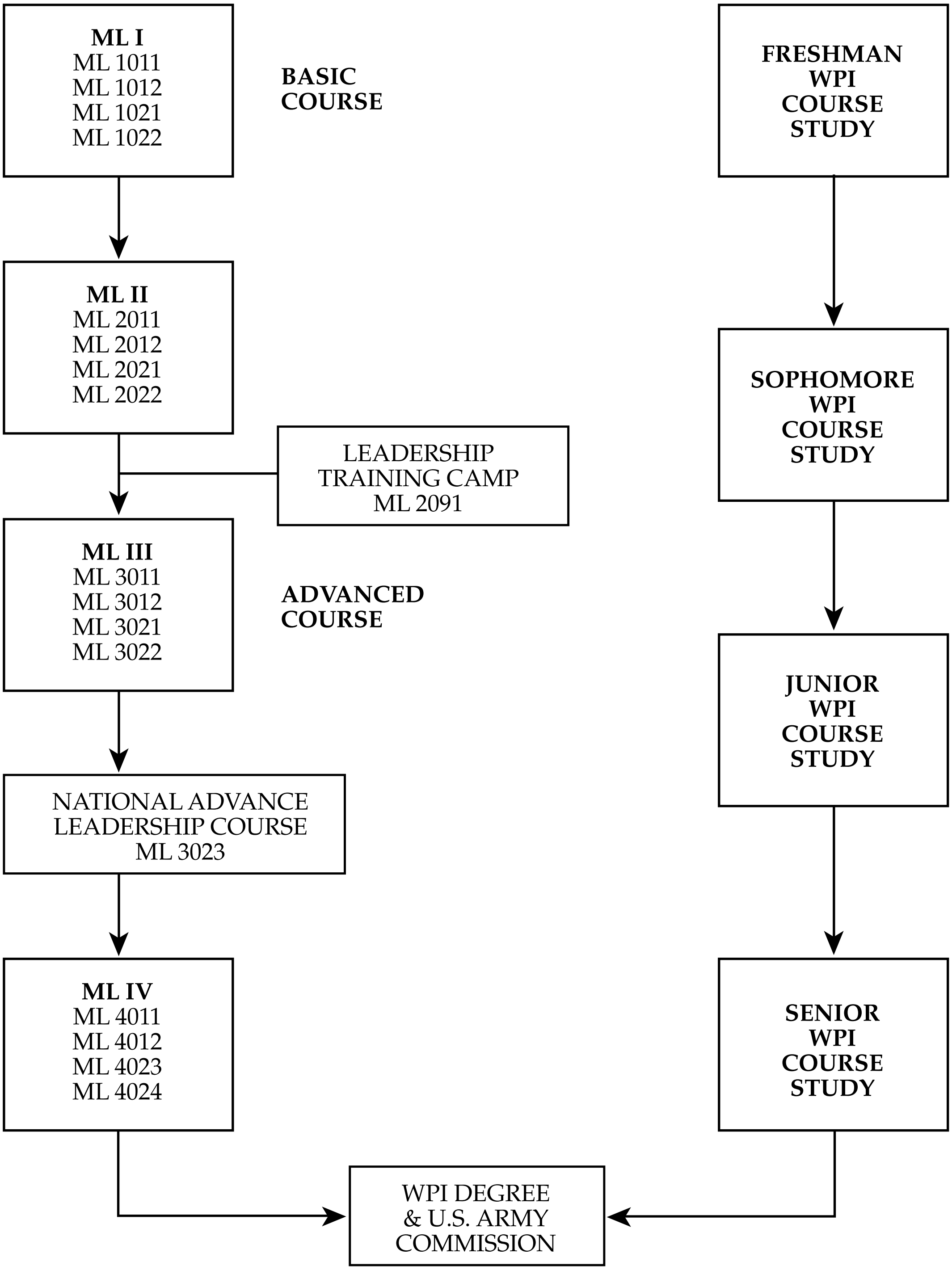
The Army Reserve Officer Training Corps (ROTC) is offered by WPI and is available to all male and female students within the Worcester Consortium. Physically qualified American citizens who complete the entire four-year program, concurrent with baccalaureate degree completion, may be commissioned in the United States Army, Army Reserve or Army National Guard. Emphasis throughout is on the development of individual leadership abilities and preparation of the student for a lifetime of service to the nation. The Military Science Department offers several concurrent programs designed to complement the WPI Plan. There are two variations of ROTC available to students who desire to participate:

The four-year program is an on-campus program during which students participate in required Military Science courses and activities. Students attend a six-week National Advanced Leadership Camp (with pay) between the third and fourth year for practical application of classroom instruction.

The two-year ROTC program begins with a six-week Leader Training Course (with pay). Upon successful completion of LTC, the student enters the third year of ROTC and will attend NALC during the following summer. If a student completed Basic and Advanced Individual Training with the U.S. Army, he/she can qualify for the two-year ROTC program.

All Military Science courses are open to any interested student without incurring any military obligation. Military Science courses are an excellent medium for personal enrichment and development of leadership abilities.

MILITARY SCIENCE COURSE FLOW CHART



(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 Basic Course includes classroom instruction and practical application opportunities which introduce the student to the Army and the Army to the student. Since all effective leaders must understand the organization in which they will function, initial instruction is intended to create a working knowledge of the Army. Subsequent instruction deals with the study of military leadership, management and technical proficiency.

ADVANCED COURSE
The Advanced Course includes classroom instruction and practical application opportunities taught during the third and fourth years. The objective is to develop leaders; to give the cadet experience in first organizing, then managing a project; to enable the cadet to take charge of any project and to bring it to a successful conclusion. This acquired ability is useful in every human endeavor; it is essential to the military leader. In conjunction with the theoretical approach to leadership studied in class, students are required to apply their knowledge during Leadership Laboratories. The Advanced Course is open to all students who have satisfactorily completed two years in the basic course or the equivalent.

Juniors enrolled in the advanced course receive a tax-free subsistence allowance of $350 each month; seniors receive $400 monthly. Pay during the National Advanced Leadership Course (NALC), is as set by Congressional legislation. To enroll in the Advanced Course, students must execute a contract stating they will continue the course of instruction for two years and accept the commission of Second Lieutenant in the United States Army, Army Reserve or Army National Guard upon graduation.

PROFESSIONAL MILITARY EDUCATION
The required professional military education component encompasses the full four years of study. It consists of two essential parts:
1. Completion of a baccalaureate degree;
2. Undergraduate certification in the areas of written communications, military history, and computer literacy.

LEADERSHIP LABORATORY
Leadership Laboratory consists of a monthly four-hour practical exercise in leadership or military skills. It is an integral part of the annual ROTC program. The purpose of Leadership Laboratory is to give each cadet the opportunity to apply practically the theory learned during formal class periods. The senior cadets conduct the laboratory period with underclass students filling subordinate roles; level of responsibility depends upon how far they have advanced in ROTC.

The Military Science Department encourages its cadets to participate in athletics and to join other extracurricular activities in order to practice leadership theories learned in military science.

PHYSICAL EDUCATION

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

REQUIREMENTS
Qualification in physical education shall be established by completing 1/3 unit of course work or its equivalency. *Students are urged to complete this requirement in their first two years of residency at WPI*. Such an equivalency may be satisfied through the PE 1100 series. PE 1100 is designed for students who wish to obtain PE credit through any of five different categories as listed below and may be substituted for any 1/12 unit PE course:
1. WPI approved varsity athletic team participation. Student must be registered in advance of participation.
2. Club Sports. Students must be members of a PE approved club prior to becoming eligible for physical education credit. Students must be registered in advance of participation.
3. Approved courses not offered at WPI; advance approval by the head of the Physical Education Department is necessary.
4. Individualized program at WPI; advance approval by the head of the Physical Education Department is necessary.
5. Proficiency testing is available in some areas; arrangements should be made with a Physical Education Department instructor.

Students who wish to obtain PE credit by the above means must be enrolled in a course in the PE 1100 series.

No student may use any 1/12-unit PE courses beyond the four required 1/12 unit to satisfy any other requirement, or to meet the 15-unit rule.

Participation in certain ROTC programs may entitle students to a waiver of the PE requirement.

ATHLETIC PROGRAMS

THE INTERCOLLEGIATE PROGRAM
The intercollegiate athletics program offers competition in 21 varsity sports.

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

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

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

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

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

Varsity Sports

Baseball	Soccer (men)
Basketball (men)	Soccer (women)
Basketball (women)	Softball
Crew (men)	Swimming & Diving (men)
Crew (women)	Swimming & Diving (women)
Cross Country (men)	Tennis (men)
Cross Country (women)	Tennis (women)
Field Hockey	Track (men)
Football	Track (women)
Golf (fall and spring)	Volleyball (women)
	Wrestling

THE CLUB SPORTS PROGRAM

The Club Sports Program offers a variety of competitive activities for student participation. Most of the Club Sports listed below compete against teams from other institutions.

Club Sports

Alpine Skiing	Lacrosse (men/women)
Cheerleaders	Martial Arts (SOMA)
Coed Soccer	Rugby
Fencing	Scuba
Free Style Wrestling	Ultimate Frisbee
Ice Hockey	Volleyball (men)
	Water Polo

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

THE INTRAMURAL PROGRAM

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

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

The program includes flag football, floor hockey, volleyball, cross-country, basketball, swimming, soccer, water polo, softball, bowling, table tennis, and track. The program is ever-expanding, and activities are added as needs arise and time and facilities permit.

The program is administered by the Department of Physical Education and Athletics, and all details regarding scheduling and eligibility are available in the Director of Intramurals located in Alumni Gym.

PHYSICS

T. H. KEIL, HEAD

PROFESSORS: S. N. Jasperson, T. H. Keil, D. F. Nelson, G. D. J. Phillies, L. R. Ram-Mohan

ASSOCIATE PROFESSORS: P. K. Aravind, N. A. Burnham, R. S. Quimby, S. W. Pierson, L. C. Lew Yan Voon, A. A. Zozulya

ASSISTANT PROFESSORS: G. S. Iannacchione, C. Koleci

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.

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.

EDUCATIONAL 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. Understand options for careers and further education, and have the necessary educational preparation to pursue those options.
5. Have an ability to learn independently.
6. Have acquired the broad education envisioned by the WPI Plan.
7. Are prepared for entry level careers in a variety of fields, and are aware of the technical, professional, and ethical components.
8. Are prepared for graduate study in physics and/or other fields.
9. Can find, read, and critically evaluate selected original scientific literature.

INTRODUCTION

Ask a physicist what physics has to do with, and you are likely to be told: "Everything!" Though oversimplified, this answer does contain a kernel of truth. In their study of nature, physicists concern themselves with interactions involving matter and energy of every form.

Physicists' interests range from the tiny world of subatomic particles to stars, galaxies and the vast cosmic sea of space and time in which they travel. They have developed intricate tools to assist the human senses in probing these remote extremes of our natural environment. They have distilled their understanding of nature into laws of great generality and elegance, from the mathematical patterns needed to interpret the perfect symmetry and the regularity of atoms and crystals, to the powerful mathematical treatment of chaos and disorder needed to deal with the concept of heat.

Of course, not all physicists work at the very limits of our knowledge of nature. Many use their understanding of physics to develop practical applications that solve more familiar human problems. The pioneering work on semiconductors in the 1940s led to the development of computers, transistor radios and a communication network that is bringing the peoples of the world ever closer together. The laser, invented in the 1960s, has been used in such varied applications as eye surgery and radar, and even in computerized cash registers. The list of problems solved is long; the list of future possibilities is endless. So there is some truth in the statement that "physics has to do with everything."

One of the distinguishing characteristics of the physicist's approach is a cyclical growth pattern. Systematic experiments provide new facts. New theory is developed to summarize these facts and make them manageable. The new theory has as its consequences practical applications and new questions, leading to new experimentation. Along the way, physicists are guided by certain fundamental principles such as symmetry, continuity and conservation laws.

Students come to the study of physics from many backgrounds and for many reasons. Two aspects in particular seem to attract them. The first is the opportunity to choose from a wide range of intriguing subjects of study, both theoretical and experimental, both fundamental and applied. The second is the combination of intuitive ideas and the penetrating style of logical and mathematical problem-solving which students come to realize physics "has to do with."

CAREER OPPORTUNITIES IN PHYSICS

Undergraduate physics programs were once formulated with the expectation that graduating students would enter postgraduate programs, where they would earn an advanced degree under the guidance of a practicing physicist. The long-term career objective was assumed to be a permanent position in an academic physics department, with interests divided between scientific research and teaching. Although this traditional outlook is still valid for many students entering the study of physics today, the unprecedented worldwide growth of science-based industries has led to exciting new career opportunities involving pure physics mixed with engineering and applied science. Many technically oriented students have also a deep interests in pure science; they are attracted to applied physics because it allows them to satisfy their scientific curiosity while at the same time pursuing the practical objectives of an engineer. In recognition of this new career choice the physics department offers a degree in engineering physics in addition to the traditional physics program. As shown in the sample programs below, students for this degree have great freedom to shape their program to match their individual interests.

AREAS OF FACULTY INTEREST (PROJECT AND INDEPENDENT STUDIES)

P. Aravind	Quantum optics, quantum mechanics, group theory.
N. Burnham	Atomic force microscopy, nanomechanics
G. Iannacchione	Calorimetry, liquid crystals
S. Jasperson	Optical properties of solids, optical instruments.
T. Keil	Solid state physics, mathematical physics, fluid mechanics.
C. Koleci	Physics education research.
L. Lew Yan Voon	Solid state physics, semiconductors
D. Nelson	Optical and transport properties, solid state physics, lattice dynamics.
G. Phillies	Light scattering spectroscopy, complex fluids, biochemical physics.
S. Pierson	Statistical mechanics, super conductivity.
R. Quimby	Optical properties of solids, laser spectroscopy.
L. Ram-Mohan	Field theory, many body problems, solid state physics, linear and non-linear optical properties of semiconductors, computational physics.
A. Zozulya	Non-linear optics, photo-refractive materials

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 22), completion of a minimum of 10 units of study is required in the areas of mathematics, physics, and related fields as follows:

PHYSICS

Requirements	**Minimum Units**
1. Mathematics (Note 1).	3
2. Physics (including the MQP; may include ES 3001) (Note 2).	5
3. Other subjects to be selected from mathematics, science, engineering, computer science, and management (Note 2).	2

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 1/3 unit of PH 2651, or other laboratory course approved by the department Program Review Committee following petition by the student.

ENGINEERING PHYSICS

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

Curriculum Outline — Physics and Engineering-Physics

The programs of study described below are designed to fulfill the needs and interests of students over the range from "pure" to "applied," or "engineering" science. They are designed to provide, first of all, a foundation in the indispensable principles and techniques of classical and modern physics. Such preparation is necessary and appropriate for any future in science and technology, including that of post-graduate study and research. Moreover, insofar as appropriate within an undergraduate curriculum, programs are offered which allow options of special experience in some of the active areas of applied or engineering physics.

All programs include a common group of recommended core courses which provide the foundation, beginning with the great themes of physics—matter, motion, forces, energy, and the nature and concepts of electricity and magnetism. They build on that basic knowledge and perspective together with progressively more sophisticated mathematical techniques. Beyond this essential core, a student may choose either a more traditional program of physics study or one relating to an area of individual interest with engineering applications. Illustrations of these options are outlined in the section below, "Physics and Engineering-Physics Programs."

Guidance in the planning of students' programs will be provided by academic advisors. A departmental engineering-physics coordinator is also available for consultation by students and academic advisors on questions pertaining to curriculum and project matters.

In addition to the courses, the Major Qualifying Project (MQP) has the potential to provide valuable experience and to broaden students' perspectives in the chosen subject area—this is one of the exceptional opportunities uniquely associated with the WPI Plan. In the case of students concentrating in one of the engineering-physics fields, the project topic would be chosen for its relevance to that area of interest. Additional information about the MQP is presented in the section on page 156, "Project Opportunities in Physics and Engineering-Physics."

Students who feel that their interests and objectives do not fit naturally into any of the illustrative programs presented here are invited to consult with their academic advisors and with representatives of the Physics Department. It is usually possible to adapt a program to their individual needs.

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.

MA 1021 Calculus I	⟷	PH 1110 Mechanics
MA 1022 Calculus II	⟷	PH 1120 Electricity and Magnetism
MA 1023 Calculus III	⟷	PH 1111 Mechanics
MA 1024 Calculus IV	⟷	PH 1121 Electricity and Magnetism
MA 1023 Calculus III	⟷	PH 1130 Introduction to 20th Century Physics
MA 1024 Calculus IV	⟷	PH 1140 Oscillations and Waves
MA 2051 Differential Equations	⟷	PH 2202 Intermediate Mechanics II
MA 2071 Linear Algebra		PH 2651 Physics Laboratory
MA 2251 Vector/ Tensor Calculus	⟶	PH 2301 Electromagnetic Fields I
MA 4451 Boundary	⟷	PH 3301 Electromagnetic Theory
Value Problems } (PH 1110, PH 1120)	⟶	PH 3401 Quantum Mechanics I PH 4206 Statistical Physics Students needing a somewhat more gradual introduction and an opportunity to gain mathematical skills concurrently are advised to substitute these courses for PH 1111 and PH 1121.

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 (EE 2201 and 3204, and digital (EE 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 1005 and CS 2005). Physics students will need to make skillful use of computers in present and future experimental data processing, theoretical analyses, and the storing, retrieving and displaying of scientific information.
- Engineering courses related to science. Some basic knowledge in areas such as heat transfer, control systems, fluid mechanics, stress analysis and similar topics will prove to be of great benefit to the physicist called upon to apply professional knowledge to practical engineering problems.

Building on this core and topical subject coverage, physics students are in a position to turn in any number of directions within the range of physics studies, depending on individual interests and career objectives. Six illustrative examples are outlined below. In each case the outline includes a list of recommended and related courses followed by a sampling of project opportunities in the respective areas. Selection of specific courses and projects should be determined by students' interests and the guidance of their academic advisors and the engineering-physics coordinator. For courses outside of the physics department, students are advised to discuss the prerequisites with the instructor.

1. Physics

Recommended Courses

PH 3402 Quantum Mechanics II
PH 4201 Advanced Classical Mechanics
PH (IS/P) Selected Readings in Physics

Related Courses

EE 2311 Continuous-Time Signal and System Analysis
EE 2312 Discrete-Time Signal and System Analysis
EE 3801 Advanced Logic Design
EE 3901 Semiconductor Devices
ES 3011 Control Engineering I
PH 3117 Problem Solving Seminar
PH 3501 Relativity
PH 3502 Solid State Physics
PH 3503 Nuclear Physics
PH 3504 Optics
PH (IS/P) Modern Optics
PH 501 (Graduate) Mathematical Methods of Physics I
PH 511 (Graduate) Classical Mechanics
MA 4291 Applicable Complex Variables

2. Computational Physics.

Recommended Courses

MA 3257 Numerical Analysis I
MA 4411 Numerical Solutions of Differential Equations
PH (IS/P) Numerical Techniques in Physics

Related Courses

PH 3117 Problem Solving Seminar
PH 3402 Quantum Mechanics II
PH 3502 Solid State Physics
PH 501/2 (Graduate)Mathematical Physics
MA 4033 Numerical Methods for Calculus and Differential Equations
MA 4291 Applicable Complex Variables
CS 1005 Introduction to Programming
CS 2005 Techniques of Programming
CS 2011 Introduction to Computer Organization and Assembly Language
CS 4731 Computer Graphics
EE 2311 Continuous-Time Signal and System Analysis
EE 2312 Discrete-Time Signal and System Analysis
EE 3801 Advanced Logic Design
ES 3011 Control Engineering I

3. Optics

Recommended Courses

PH 3504 Optics
PH 2501 Photonics
PH 2502 Lasers

Related Courses

PH 3117 Problem Solving Seminar
PH 3402 Quantum Mechanics II
PH 3502 Solid State Physics
PH 542/3 (Graduate) Modern Optics I and II
MA 4291 Applicable Complex Variables
ID 3150 Light, Vision, and Understanding
EE 2311 Continuous-Time Signal and System Analysis
EE 2312 Discrete-Time Signal and System Analysis
ES 3011 Control Engineering I

4. Electromagnetism

Recommended Courses

PH (IS/P) Modern Optics
PH (IS/P) Selected Readings in Electromagnetism

Related Courses

PH 3117 Problem Solving Seminar
PH 3402 Quantum Mechanics II
PH 3502 Solid State Physics
PH 3503 Nuclear Physics
PH 3504 Optics
PH 533 (Graduate) Electromagnetic Theory
PH 514/5 (Graduate) Quantum Mechanics
MA 4291 Applicable Complex Variables
EE 2311 Continuous-Time Signal and System Analysis
EE 2312 Discrete-Time Signal and System Analysis
ES 3011 Control Engineering I

5. Nuclear Science And Engineering

Recommended Courses

ES 2011 Introduction to Nuclear Technology
PH 3503 Nuclear Physics

Related Courses

PH 3117 Problem Solving Seminar
PH 3402 Quantum Mechanics II
PH 3501 Relativity
PH 553 (Graduate) Nuclear Physics
ME 4832 Corrosion and Corrosion Control
EE 3801 Advanced Logic Design
ES 3011 Control Engineering I

6. Thermal Physics

Recommended Courses

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

Related Courses

ES 3003 Heat Transfer
ES 3011 Control Engineering I
PH 3117 Problem Solving Seminar
ME 3410 Compressible Flow
PH 3502 Solid State Physics
PH 3504 Optics
ME 4429 Thermodynamic Applications and Design
ME 4602 Intermediate Fluid Dynamics
PH 501/2 (Graduate) Mathematical Physics

Project Opportunities in Physics and Engineering-Physics

Opportunities for physics students to participate in theoretical, computer-aided or experimental research exist in numerous fields, including nuclear and particle physics, modern and classical optics, statistical and solid-state physics, electromagnetism, astrophysics, field theories, and in the great range of subfields within these categories.

In the engineering-physics programs, the MQP subject is generally chosen for its relevance to the particular area of concentration. Students usually obtain the assistance of their academic advisors and of the engineering- physics coordinator in arranging the project. It may also include the participation of a project coadvisor who is a member of the engineering faculty.

Information for the selection of a Major Qualifying Project (MQP) by physics and engineering-physics students can be obtained from physics faculty members at any time during the academic year, and especially during the

Term C project planning period. A project resource booklet, available in the department office, provides MQP subject information, identification of participating faculty and their areas of interest, and data relating to past projects. Physics faculty serve as project advisors on MQPs in their own fields of research, and sometimes in other appropriate scientific areas of mutual student-advisor interest.

For all physics and engineering-physics students, there are opportunities for off-campus projects in industries, hospitals, research institutions, government and other resources in the Worcester vicinity and beyond. Information on these possibilities, which are constantly changing and expanding, is managed and made available to students and faculty on the Projects Program web site.

PHYSICS FOR NONPHYSICS MAJORS

Physics is the scientific underpinning for all engineering work and is therefore considered by prospective engineers, almost without exception, to be a subject which merits serious study. The elementary physics sequence at WPI encompasses the subject areas of classical mechanics (PH 1110/PH 1111), electricity and magnetism (PH 1120/PH 1121), 20th century physics (PH 1130), and oscillation and wave phenomena (PH 1140). The sequence is designed to be taken either in the pattern PH 1110, 1120, 1130, 1140, or PH 1111, 1121, 1130, 1140, although other orderings are possible, depending on special circumstances.

The first two courses in this sequence are offered in two versions because of the diversity of backgrounds and preparation of entering students. PH 1111 and PH 1121 are aimed primarily at freshmen with a solid background in the sciences and in mathematics, including calculus. In particular, students in PH 1111 and PH 1121 should be able to differentiate and integrate elementary trigonometric and polynomial functions, and to interpret these operations in graphical form. PH 1110 and PH 1120 are taught at a mathematically less demanding level and are designed for students concurrently beginning their study of calculus, having had little or no college-level calculus preparation in high school.

The courses in classical mechanics and electricity and magnetism are regarded as essential preparation for many fundamental engineering courses as well as for further work in physics. PH 1130 gives a first introduction to 20th century physics: the theory of relativity, quantum physics, nuclear physics and elementary particles. It is designed to provide a context for the appreciation of present-day advances in physics and high-technology applications. PH 1140 deals in depth with oscillations and waves. Engineering applications of this subject reach all the way from LC circuits and electromagnetic wave propagation in electrical engineering to the vibrations of large scale structures such as machinery and highway bridges in mechanical engineering and civil engineering.

There are several intermediate physics courses that may be of interest to nonphysics majors. PH 2201-2202 give a physicist's view of mechanics which to mechanical engineering majors may be an interesting and useful complement to the engineering courses in statics and dynamics. The physics courses in quantum mechanics, PH 3401-3402, and solid state physics, PH 3502, may be of great interest to electrical engineering students specializing in solid state electronics. The courses in electromagnetic field theory, PH 2301 and PH 3301, and optics, PH 3504, would provide a valuable background for students in many areas, such as modern communication systems, fiber optics and optical computing. These are just examples; other courses are also available. For specific information on individual courses, students may consult with the course instructor or with the Physics Department head.

PHYSICS MINOR

The Physics Minor offers non-Physics majors the opportunity to broaden their understanding of both the principles of physics and the application of those principles to modern day engineering problems. In these times of rapid technological change, knowledge of fundamental priciples 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 ar all of the following four introductory courses:
   PH 1110 or PH 1111
   PH 1120 or PH 1121
   PH 1130
   PH 1140
2. At least 2/3 unit of upper level physics courses (2000 level or higher), which may include IS/P courses or independent studies approved by the program review committee. Examples of courses of this type which might be selected are (but are not limited to):

PH 2201	Intermediate Mechanics I
PH 2301	Electromagnetic Fields
PH 2651	Physics Laboratory
PH 3401	Quantum Mechanics I
PH 3504	Optics
PH 2501	Photonics
IS/P	Quantum Engineering

Students who have taken the four course introductory sequence should have an adequate physics background for these courses; see, however, the individual course descriptions for the expected mathematical background. Other physics courses may be selected for the physics minor, but the reccommended background for such courses often includes one or more of the courses listed above.

3. Capstone Experience

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

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

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

PRE-LAW PROGRAMS

ADVISORS: G. HEATON, K. RISSMILLER

Law schools do not require that undergraduates complete any particular course of study. Thus, students who complete degrees in engineering and science may wish to consider careers in law. Undergraduates interested in attending law school are encouraged to choose from among the many courses offered which explore legal topics. For those with greater interest, WPI offers a Minor in Law and Technology described on page 121. Courses with substantial legal content are listed among those courses fulfilling the requirements of the minor.

Enrolling in these courses will introduce students to the fundamentals of legal process and legal analysis. Students will study statutes, regulations and case law. These courses will, therefore, offer the student valuable exposure to the kind of material commonly studied in law schools and they may help demonstrate a student's interest to law school admission committees. IQPs in Division 52, Law and Technology, or other projects that involve library research and extensive writing may also be helpful.

A pre-law advising program in the Social Science Department maintains information on careers in law, law schools, and the law school admission test (LSAT), which is universally required. Students may examine this material independently or make an appointment. Students with an interest in law are also encouraged to join the Pre-Law Society. To do so, contact Professor Rissmiller.

PRE-MBA PROGRAM (DUAL DEGREE)

ADVISOR: N. WILKINSON

A B.S./MBA program is available to outstanding WPI undergraduate students majoring in an engineering or science discipline. A separate and complete application to the MBA program must be submitted. Admission to the Combined Program is determined by the faculty of the Department of Management. The student should begin the curriculum planning process at the time he/she commences his/her undergraduate studies to ensure that all of the required prerequisite undergraduate courses are completed within the student's four years of undergraduate study. It is recommended that the MBA application be submitted at the beginning of the student's junior year of undergraduate study. A student in the Combined Program continues to be registered as an undergraduate until the bachelor's degree is awarded.

Students wishing to do a Combined B.S./MBA must complete the following courses while an undergraduate: MG 1100 *Financial Accounting;* MG 2200 *Financial Management;* MG/IE 2300 *Organizational Science;* MA 2611 *Applied Statistics I;* MA 2612 *Applied Statistics II;* MG/IE 3400 *Production System Design;* MG 3600 *Marketing Management;* MG 3700 *Information Systems Management;* SS 1110 *Introductory Microeconomics;* SS 1120 *Introductory Macroeconomics.* To obtain a bachelor's degree via the Combined Program, the student must satisfy all requirements for the bachelor's degree, including distribution and project requirements.

To obtain an MBA via the Combined Program, the student must satisfy all MBA degree requirements. In addition to the prerequisite undergraduate courses listed above, the student must complete the following graduate courses: MG 511 *Interpersonal and Leadership Skills for Technological Managers;* MG 512 *Creating and Implementing Strategy in Technological Organizations;* MG 513 *Creating Processes in Technological Organizations;* MG 514 *Business Analysis for Technological Managers;* MG 515 *Legal and Ethical Context of Technological Organizations;* MG 516 *Graduate Qualifying Project (GQP);* 12 Elective Credits.

For more information on this program, contact N. Wilkinson, Washburn 218, (508) 831-5957.

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

ADVISOR: J. RULFS

Planning a program in one of the pre-health professions at WPI should be done in consultation with the WPI faculty pre-health professions advisor, Prof. J. Rulfs, Salisbury Labs 233. Entry into medical or other health professional schools may be accomplished through any major program of study at WPI. However, evidence that the student is interested in medicine and biology must be presented to the professional schools during the application process. For this reason, students, regardless of major, should plan their academic programs to include courses in biology, general and organic chemistry, and physics including laboratory experiences.

Students interested in becoming veterinarians should consider applying for admission to the joint B.S./D.V.M. program offered by WPI and Tufts University School of Veterinary Medicine. Students entering this program are guaranteed admission to veterinary school as early as the high school senior year and in addition can complete the entire program in seven years, rather than the traditional eight.

The formalized WPI projects program offers a tremendous advantage to pre-health professional students. Medical, dental, and veterinary schools view independent study and participation in research with great favor. At WPI, all students, rather than a select few, participate in such activities. The IQP and MQP are excellent examples. Most IQPs and MQPs done by WPI pre-health professions students are health-related, and many are done at off-campus medical settings such as the University of Massachusetts Medical Center or, the Tufts School of Veterinary Medicine.

A typical pre-medical or pre-dental program should include:

Introductory chemistry	3 courses
Organic chemistry	3 courses
Biology	3 courses
Physics	3 courses
Mathematics	3 courses
English Composition	2 courses*

Science courses should include laboratory segments.

*Check with the pre-health advisor for use of Humanities and Arts courses in lieu of composition requirement.

Students should consult medical or other professional school catalogs for specific admissions requirements. Students majoring in certain programs may have to utilize all of their electives to fulfill pre-health course requirements and/or may have to take some courses during summer sessions.

Grades in undergraduate courses, especially science courses, are important to medical, dental, and veterinary schools. Applicants usually have to submit a "cumulative quality point average" calculation. Such a calculation is performed by the Registrar upon written request by the student.

Students aspiring to enter one of the health professions should also plan alternative careers. Nationally only about one out of three qualified applicants is accepted into medical school, and veterinary schools are even more selective. Many WPI pre-health students have been successful in their applications to professional schools. However, it is important to realize that all WPI graduates have a degree in a major program of study and are thus well qualified to pursue a career in that alternative area.

SOCIAL SCIENCE AND POLICY STUDIES

K. SAEED, HEAD
PROFESSORS: J. T. O'Connor, K. Saeed
ASSOCIATE PROFESSORS: J. K. Doyle, M. J. Radzicki, K. J. Rissmiller, J. M. Wilkes
ASSISTANT PROFESSOR: O. Pavlov, E. A. Weaver
PROFESSOR OF PRACTICE: J. Lyneis
ADJUNCT FACULTY: W. Baller, G. Heaton, B. Karanian
AFFILIATED FACULTY: D. Meadows

MISSION STATEMENT

SSPS programs are concerned with the substance and the process of socioeconomic problem solving especially as related to technological development, environment and public policy. Most socioeconomic problems - e.g., inflation, unemployment, urban deterioration, environmental pollution, income inequality, or infrastructure creation and maintenance - go beyond the boundaries of the traditional social science disciplines. Hence, the courses offered by the Department of Social Science and Policy Studies attempt to integrate knowledge and research techniques from multiple disciplines. Our curriculum covers system dynamics, economics, sociology, psychology, law and political science. System dynamics exclusively focuses on a computer modeling and experimental analysis approach to problem solving and policy analysis while other areas employ a variety of modeling and analysis methods including system dynamics. The department also encourages students to view social and economic problems, and the relationship of technology to society, from a variety of perspectives and to become acquainted with different methods of gathering and analyzing social data.

SSPS department offers undergraduate majors in several policy related disciplines. In addition, the department administers WPI's two-course requirement in Social Sciences.

EDUCATIONAL OUTCOMES

Graduates of a social science major must have demonstrated through coursework and projects:

1. An ability to recognize patterns in real world data, qualitative and quantitative, in order to be able to define problems.
2. An ability to formulate hypotheses and models representing problems and understand their logic.
3. An ability to experiment with such models to establish their validity.
4. An ability to carry out exploratory analysis to arrive at remedial instruments addressing the defined problems.
5. Literacy in the technical aspects of a problem in the student's area of concentration.
6. An ability to effectively communicate the results of an analysis.
7. An ability to work with groups.
8. Computer literacy.

The teaching of social sciences differs from engineering in that it must deal with a large variety of empirical manifestations in the face of unreliable and often local theoretical premises. Thus, while a bulk of engineering practice involves applying well known physical principles to the design of physical systems, much time must be spent in social science analysis in recognizing problems, understanding their underlying relationships and developing premises to deal with the stylized facts. Once a problem is recognized, a vehicle of analysis must be developed to understand it and develop a remedial process. The validation of social analysis draws on the well-known principles of the scientific method, although the mechanics of its implementation vary depending on the vehicle of analysis used.

SSPS course offerings attempt to address the above agenda by focusing on description and analysis rather than only on prescription. Methodology and its valid practice are covered extensively in the system dynamics courses, while in other offered courses, research methods are integrated with the discipline-related content. Many courses emphasize group work in one form or the other. Item 5 above is addressed through coursework in other departments offering relevant curricula. Interactive Qualifying Project (IQP) and Major Qualifying Project (MQP) offer opportunities for learning the problem solving process in a real world context.

MAJOR PROGRAMS

The department offers majors in system dynamics, economics, economics and technology, environmental policy and development, and society-technology and policy. Please see the respective program coordinator for advice on the major you are interested in.

SYSTEM DYNAMICS

Coordinator: Prof. James M. Lyneis

The system dynamics major is aimed at developing the craftsmanship and the multi-disciplinary skills needed for computer modeling and experimental analysis of complex socioeconomic and technical problems encountered in private and public organizations. It prepares students for careers in public and private sector organizations maintaining in-house planning and problem solving groups, as well as for careers in public and private sector consulting firms. The fundamental focus of the program is on system dynamics as a problem-solving methodology and on training students to apply system dynamics to a wide range of problems experienced in engineering, economic and societal systems. The application areas of the program are designed to create opportunities for students to apply computer modeling and experimental analysis to specific problems, so that they can develop both expertise in those areas and the methodological skills necessary for applying the technique to other application areas. The major responds to the need for integrating specialized skills to address multidisciplinary problems created by the interaction of society and technology.

ECONOMICS

Coordinators: Prof. Michael J. Radzicki and Prof. Oleg V. Pavlov

Students majoring in economics prepare for careers in public administration, labor-management relations, or the economic, finance, international, sales, and general management areas of industry. This major also provides an excellent foundation for graduate study not only in economics, but in business and law as well. Students majoring in economics would ordinarily begin their studies in the basic theory areas: analysis of macroeconomic problems and public policy, analysis of problems of the firm and market organizations. In addition, to develop a capability in the area of economic modeling, students should study econometrics and system dynamics. Econometrics deals with the techniques used by economists to test hypotheses and to estimate functional relationships quantitatively. System dynamics allows development and testing of theoretical relationships and developing policy scenarios.

In addition to gaining proficiency in general economic analyses by completing the course in basic theory, students will undertake studies and project work in more specialized fields of study. The choice of fields will, of course, reflect the needs and motivation of the individual. It is probable that the interest of many students will fall within one or more of the traditional specialized fields of study, or in one of the new areas of inquiry recently introduced. Several of the more important of these fields are economic growth and stability, industrial organization and public policy, environmental economics and resource management, economic development, urban and regional planning, and international economic relations.

ECONOMICS AND TECHNOLOGY

Coordinator: Prof. Michael J. Radzicki

Economics has traditionally been viewed as an excellent preparation for careers in law, public service, and general management in business and government. According to the United States Bureau of Labor, employers specifically listed a major in economics as a good background for careers in a wide variety of administrative and sales areas. Students who are beginning careers directly out of college will find that the study of technology will provide an invaluable supplement to their training in economics in many occupations. Future graduates of the department's program in economics and technology will be desired by firms looking for managers possessing the technological knowledge of the engineer and the decision making perspectives and modeling skills of the economist. Examples of such firms include:

1) pharmaceutical companies needing managers to analyze drug markets and interact with chemists and chemical engineers, 2) investment banking houses and brokerage firms needing analysts and brokers with the technological literacy necessary to assess high technology firms and their market prospects, and 3) public utilities needing managers capable of forecasting electricity demands and conducting cost benefit analyses of alternative methods of acquiring generating capacity.

The Economics and Technology major is an ideal preparation for graduate education, particularly the MBA. Study of the functional areas of management and specific managerial skills consume so much of an MBA program that only minimal time remains for study in other important areas including economics. However, a thorough understanding of economics is critical for all types of businesses and government agencies. Moreover, the ability to understand a business firm's technical production processes and products is also important in many areas of Management. Clearly, both halves of the Economics and Technology program complement the preparation for the business world provided by graduate programs in business. The E&T major provides training in areas that are important for success in business but are largely and wholly neglected in graduate business programs. Students enrolled in the Economics and Technology program offered by the Department of Social Science and Policy Studies at WPI will study economic theory and model building at both the micro and macro levels as well as techniques for economic decision making and the collection and analysis of economic data. Macroeconomic theory explains the behavior of the economy in the aggregate, while microeconomic theory deals with the behavior of individual firms, consumers and markets. The economics portion of the program includes courses in economics and related subjects in management and the other social sciences. These cover basic economic theory and its applications in such areas as the environment, health care, industrial organization, fiscal and monetary policy, as well as quantitative methods.

The program's technical component comprises courses roughly evenly divided between basic science and math preparation and courses in an engineering or science major. The aim is to acquaint students with the work of professionals in the technical discipline, ensure that they are conversant with the field, and familiar with its terminology and basic principles. Course sequences providing this preparation have been identified for twelve engineering and science disciplines, including computer science and mathematics.

ENVIRONMENTAL POLICY AND DEVELOPMENT
Coordinators: Prof. Khalid Saeed and Prof. Kent Rissmiller
During the past decade, the daily news has become increasingly filled with stories of economic stagnation and environmental destruction. As a result, interest in the environment and its impact on households, firms, cities, regions, and nations has been rekindled among students, the public at large, and within private firms and the government.

At the university level, environmental issues can be studied in a number of ways. They can, for example, be studied from a technological perspective via the natural and engineering sciences, or from a policy perspective via the management and social sciences. Indeed, environmental programs at many universities examine environmental issues in precisely these ways. It is unusual, however, for an environmental program to offer a strong education from both the technical and policy perspectives. The Department of Social Science & Policy Studies at WPI fills this gap by offering a baccalaureate degree in the area of Environmental Policy and Development (EP&D). This degree program offers students substantial technical and policy education on environmental issues. An important feature of WPI's EP&D major is its focus on the interaction between the environment and the economy. On June 14, 1992, during the so-called "Earth Summit" in Rio de Janeiro, the United Nations Conference on Environment and Development adopted Agenda 21, a document that calls upon the nations of the world to "take a balanced and integrated approach to environment and development questions." The EP&D major has adopted sustainable economic development as one of its organizing themes. That is, many traditional environmental issues are examined through the lens of sustainable development.

The term sustainable development means choosing policies that balance environmental preservation and economic development so as to meet the needs of the present generation without compromising the needs of future generations. The global ecological-economic system is essentially "closed." This means that, except for the receipt of solar energy from outer space and the dispersion of heat to outer space, the system is self-contained. The people living in the global system use both nonrenewable and renewable resources (which are limited) to produce goods and services that sustain and enhance life on the planet. Unfortunately, the process of creating goods and services also generates pollution that must be dispersed into the land, sea, and air. The amount of pollution that these "sinks" can absorb is also limited.

For the global system to sustain itself indefinitely, renewable resources must not be used faster than the rate at which they can be regenerated, nonrenewable resources (taking recycling into account, which is also a limited process) must not be faster than the rate at which they can be substituted for, and pollution must not be generated faster than the rate at which the system can absorb it. WPI's program in EP & D 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.

SOCIETY, TECHNOLOGY AND POLICY
Coordinator: Prof. John M. Wilkes
The Society Technology and Policy major at WPI is designed for those who wish to prepare for a career in which they will deal with our society's critical problems. Great challenges face our society and many of the major ones stem from the interplay of technology and society. Environment, energy, productivity, population, education, defense, and global competition are all recognized as policy areas in which technological change is playing an important role. To address such problems, policy makers and analysts must be technically literate and familiar with the tools of analysis in the social ills both as a cause and, potentially, as a cure. This is precisely the background and knowledge that the Society, Technology and Policy program seeks to provide. In the STP program students major in social science and minor in a science or engineering discipline of their choice. Over a dozen technological alternatives are available including: biotechnology, computer science, manufacturing engineering, and management. Students take courses in at least two social science disciplines: economics, political science, psychology, and sociology. The social science coursework will emphasize policy issues and the study of the ways in which science and technology shape society and, conversely, the ways in which social forces affect the development of technology.

As a major in this program, a student will benefit from WPI's project oriented approach to learning. Students use project opportunities to engage in in-depth research on social policy issues and the interactions between society and technology. They may carry out their projects on the WPI campus, at any number of local agencies or corporations, or at one of WPI's off campus project programs in the United States and abroad. Through this interdisciplinary program the student will acquire the social science background needed to understand contemporary public policy, to interpret technical materials produced by physical scientists, engineers and social scientists and to be able to synthesize these materials for policy considerations on the part of government and industry. Graduates of this program will be valuable additions to the administrative or research staffs of a variety of businesses, regulatory agencies, government departments or contract research organizations.

Program Distribution Requirements for the System Dynamics, Economics, Economics and Technology, Society Technology and Policy, and Environmental Policy and Development Majors

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

SYSTEM DYNAMICS

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

NOTES:
1. Only social science courses with a "5" in the second digit of the course number count toward the system dynamics requirement.
2. Must include microeconomics or macroeconomics, cognitive or social psychology, and public policy.
3. Must include organizational science.
4. Must include differential and integral calculus, differential equations, and numerical or statistical analysis.
5. CS1005 and CS2005 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.

ECONOMICS

Requirements	Minimum Units
1. Economics (Note 1).	3
2. Economics and/or Management (Note 2).	1
3. Other Social Science.	1
4. Mathematics (Note 3).	2
5. Basic Science.	1
6. Electives.	1
7. MQP.	1

NOTES:
1. Must include courses in both micro and macro economic theory at the intermediate level and in international trade and econometrics (available through the Consortium or independent study).
2. Must include financial accounting, MG 1100. May include other relevant management courses as approved by the Departmental Program Review Committee.
3. Must include differential equations, integral calculus, and statistics.

ECONOMICS AND TECHNOLOGY

Requirements	Minimum Units
1. Economics (Note 1).	3
2. Management (Note 2).	2/3
3. Other Social Science.	1
4. Basic Science.	2/3
5. Mathematics (Note 3).	5/3
6. Technical Electives (Note 4).	2
7. MQP (Note 5).	1

NOTES:
1. a. Must include econometrics, systems analysis, industrial organization and intermediate level microeconomic and macroeconomic theory.
   b. Must include (1) two courses in environmental economics, the economics of the medical care industry or advanced systems analysis or (2) two courses in fiscal and monetary economics.
2. Must include financial accounting and either financial management or engineering economics.
3. Must include statistics, and differential and integral calculus.
4. Courses must be in science or engineering with a concentration in one discipline.
5. The MQP may be in Economics or in the student's technical field with the approval of the academic advisor and the departmental Program Review Committee.

SOCIETY, TECHNOLOGY AND POLICY

Requirements	Minimum Units
1. Social Science (Notes 1, 2).	4
2. Minimum Basic Science background.	2/3
3. Minimum Mathematics background (Note 3).	1
4. Technical concentration (Note 4).	5/3
5. Electives (Note 5).	5/3
6. MQP	1

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

ENVIRONMENTAL POLICY AND DEVELOPMENT

Requirements	Minimum Units (Note 1)
1. SS & PS (Note 2).	12/3
2. Mathematics (Note 3).	5/3
3. Basic Science (Note 4).	2/3
4. Technical Concentration (Note 5).	2
5. Department Electives (Note 6).	2/3
6. MQP.	1

NOTES:
1. 1/3 unit = 1 course. 15 units are required for graduation.
2. Students must complete 5/3 units (5 courses) in one of three social science areas: (a) economics, (b) psychology/sociology, (c) political science (includes SS & PS courses in law and policy analysis) and 2/3 unit (2 courses) in each of the other two social science areas. The particular courses chosen must include six out of the following nine courses: A Psychological Perspective on Environmental Problem Solving, American Public Policy, Development Economics, Environmental Economics, International Environmental Policy, Introduction to Economic Systems, Legal Regulation of the Environment, Technical Expertise in Governmental Decision Making, and the Society-Technology Debate. Students must also complete three other social science courses (1 unit) of their choosing.
3. Must include both calculus and statistics.
4. Basic science courses must be selected from the disciplines of Physics, Chemistry, or Biology.

5. The technical concentration must include at least six thematically related courses in science, engineering or management that have been approved by the Department's Program Review Committee.
6. Departmental electives must be selected from the areas of mathematics, basic science, social science, or the technical concentration.

THE SOCIAL SCIENCE REQUIREMENT

To satisfy WPI's two-course social science requirement, students may take courses in any of the traditional social sciences. They will normally begin by taking one of the introductory core courses listed below:

System Dynamics
SS 1503 The Psychology of Decision Making and Problem Solving
SS 1510 Introduction to System Dynamics Modeling

Economics
SS 1110 Introductory Microeconomics
SS 1120 Introductory Macroeconomics

Sociology
SS 1202 Sociological Concepts and Analysis
SS 1203 Social Problems and Policy Issues

Psychology
SS 1401 Introduction to Cognitive Psychology
SS 1402 Introduction to Social Psychology
SS 1503 The Psychology of Decision Making and Problem Solving

Political Science
SS 1301 U.S. Government
SS 1303 American Public Policy
SS 1310 Law, Courts, and Politics
SS 1320 Topics in International Politics

THE SECOND COURSE IN SOCIAL SCIENCE

In choosing their second course in social science, students confront a choice between taking a second introductory course in another social science discipline, or a more advanced course in the same social science discipline as the first. The department recommends the latter choice. At least two courses in a given field are essential to achieving a firm understanding of the nature of the discipline: its organization, its basic vocabulary, the way in which it approaches the solution of the problems that are its central focus, and how it seeks to explicate the phenomena with which it is concerned. Moreover, the advanced courses available at WPI have substantial theoretical and empirical components, which provide the student with an opportunity to see how social science is applied to the solution of specific public and private policy problems. These courses are listed below.

System Dynamics
SS 1520 System Dynamics Modeling
SS 2530 Advanced Topics in System Dynamics Modeling
SS 2540 Group Model Building

Economics
SS 2110 Intermediate Microeconomics
SS 2117 Environmental Economics
SS 2120 Intermediate Macroeconomics
SS 2125 Development Economics

Sociology
SS 2207 Creativity and the Scientific Community
SS 2208 The Society - Technology Debate

Political Science and Law
SS 2302 Science-Technology Policy
SS 2304 Governmental Decision Making and Administrative Law
SS 2310 Constitutional Law
SS 2311 Legal Regulation of the Environment
SS 2312 International Environmental Policy
SS 2313 Intellectual Property Law

Psychology
SS 2401 The Psychology of Education
SS 2405 The Psychological Study of Environmental Issues
SS 2406 Cross-Cultural Psychology: Human Behavior in Global Perspective
SS 2540 Group Model Building

These advanced or depth courses deal with a wide variety of subjects: system dynamics modeling and experimental analysis, government regulation of business, environmental law and economics, educational psychology, technology assessment and environmental policy and decision making, among others. This element of application in the depth courses adds greatly to students' interests in the course and their understanding of the capabilities and usefulness of the subject.

Students are advised to take both of their social science courses in the same discipline so that they may take a depth course that will provide an opportunity to study social science of specific and direct relevance to their Interactive Qualifying Projects (IQPs). Some students prefer, however, to combine courses across disciplines. In particular, a course in social science methodology like SS 1520 System Dynamics Modeling would be suitable to be taken with an introductory course in economics, psychology, sociology and political science and law. The department believes that it is critical for students to forge as close and direct a link as possible between their social science preparation and IQP. The IQP relates science and technology to society. It aims to make students sensitive to general social problems, aware of societal- humanistic-technological interactions, able to analyze these interactions and to make better judgments and policy recommendations. Given the objective of the IQP, it is not surprising that many involve analysis of social problems and the evaluation of policy options. Typically, knowledge of both technology and social science are required for effective handling of such IQPs. But in many cases, the critical skills lie in the area of social science. Technology provides the base-line level of information required to assess an impact or to evaluate options. However, the manner in which society responds to technical change is a function of our economic and political systems, of individual perceptions, attitudes and values, and the interactions of individuals and groups. All of these are the subject matter of social science. Their understanding is essential for projects that analyze societal-technological interactions and examine social policy issues, whether directly linked to technological developments or not.

The most important contribution which the study of social science can make to the education of engineering and science students is to create an awareness that knowledge of social science is vital in analyzing a wide range of problems and in making many types of decisions. It is important that, in the future, engineers and scientists not approach social impact problems guided solely by their background in technology, ignoring the previous contributions of the social sciences in these areas. The primary goal of the social science requirement is to leave engineering and science students with the recognition that social science knowledge is useful and accessible and that they are capable of mastering its tools, comprehending its approaches and applying these tools to practical problems.

If this goal is to be realized, it is highly advisable that students link their study in social science to their Interactive Qualifying Projects. The department recommends that students begin with an introductory course late in the freshman or early in the sophomore year, and follow that with an applied depth course in the sophomore or early in the junior year when the IQP topic has been identified.

COURSE SEQUENCES IN SOCIAL SCIENCE

To aid students in selecting appropriate sequences of introductory and applied courses to satisfy their social science requirement, the department has identified logical course sequences in the areas listed below.

SYSTEM DYNAMICS

Introduction to System Dynamics Modeling (SS 1510) followed by SS 1520 System Dynamics Modeling provides students with a sequence of two courses in system dynamics. The first course introduces the students to the systems thinking perspective and the techniques of modeling and experimental analysis using computer simulation. The second course deals with problem solving using system dynamics modeling. These two courses provide the basic skills for applying the system dynamics method to IQP or MQP projects. System Dynamics is an expanding process in K-12 education. This course sequence would also greatly help aspiring high school teachers to apply system dynamics in facilitating learning in their respective subject areas. For a more technical treatment of the subject, the two-course sequence may include System Dynamics Modeling (SS 1520) followed by Advanced Topics in System Dynamics Modeling (SS 2530).

ECONOMICS

Several combinations of course offerings in economics can be selected depending on the student's interest. Introductory Microeconomics (SS 1110) followed by Intermediate Microeconomics (SS 2110) would cover microeconomic theory as applied to a firm. Introductory Microeconomics (SS 1110) followed by Environmental Economics (SS 2117) would create a theoretical basis for dealing with environmental regulation and policy. Introductory Macroeconomics (SS 1120) followed by Development Economics (SS 2125) would make a succinct introduction to developmental agendas. Introductory Micro- or Macroeconomics (SS 1110 or SS 1120) followed by System Dynamics Modeling (SS 1520) would create a good window to understanding economic dynamics and disequilibrium growth.

The tools of decision-making developed in these courses find application in a wide range of IQPs. Cost analysis, investment decisions, and the forecasting of trends in consumption, production and prices are required in many IQPs dealing with energy, risk analysis, and economic growth and development.

PSYCHOLOGY

A two-course sequence in Cognitive or Social Psychology is ideal preparation for IQPs that require an understanding of how individuals or groups think when faced with social and technological problems. SS1401 (Introduction to Cognitive Psychology) and SS 1402 (Introduction to Social Psychology) are alternate introductions to experimental psychology. SS 1401 emphasizes the mental processes that individuals apply to perception, memory, learning, judgment, and problem solving tasks and their implications for education and engineering design.

SS 1402 is concerned with how people think about, feel for, and act toward other people, and covers such topics as social influence, altruistic behavior, aggression, gender differences, stereotyping and prejudice, and small group decision making. The Psychology of Decision Making and Problem Solving (SS 1503) provides students an opportunity to improve many of the cognitive skills relevant to IQPs and MQPs, including memory, problem solving, reasoning, decision making, and intelligent criticism.

Either SS 1401 or SS 1402 followed by SS 2401 (The Psychology of Education), provides a solid background for students who plan to conduct IQPs in educational settings, from pre-school through college. SS 2401 covers such topics as student diversity, the learning process, motivation to learn, and techniques for evaluating student learning. Current issues in higher education (particularly technological education) are emphasized.

The two-course sequence SS 1402 and SS 2406 (Cross-Cultural Psychology: Human Behavior in Global Perspective) is especially designed for IQP students preparing to work at international project centers, International Scholars, and students interested in the global aspects of science and technology. SS 2406 introduces students to the wide variety of social and cultural influences that shape human behavior in different parts of the world, with particular attention paid to cultural influences on technology development and transfer.

Students interested in new approaches to environmental problems should consider taking SS 1401 followed by SS 2405 (The Psychological Study of Environmental Issues). Those interested in knowledge solicitation should consider SS 2540 (Group Model Building) as a second course. SS 2405 traces the root causes of environmental problems to basic human thought processes and explores the argument that successful environmental policies must be based on an understanding of how individuals think about the environment, how pro-environmental behavior is related to environmental attitudes, and how people respond to environmental information and policies. The course emphasizes the application of psychological knowledge to the development of innovative solutions to problems such as global warming, ozone depletion, species extinction, and energy and resource conservation. SS 2540 deals with mapping and soliciting experiential information and mental models. It covers team learning, group communication and decision-making processes, and factors that promote or impede group performance.

SOCIOLOGY (SCIENCE, TECHNOLOGY, AND POLICY - STP)

Many IQP projects center on issues of social impact, technology assessment, or addressing a social problem. Some address issues specifically in the society-technology debate regarding the cultural and social trends associated with the emergence of a "technological" or "post-industrial" society. The following courses have been developed as background material for such projects. Many are also core courses in the curriculum designed for Society-Technology Majors.

The typical entry level course for those interested in SS 2208 (The Technology-Society Debate), SS 2207 (Science and Creativity), or SS 1203 (Social Problems and Policy Issues) is SS 1202 (Introduction to Sociological Concepts). However, there are two other courses that are acceptable alternatives in preparing for SS 1203 (Social Problems and Policy Issues). These are SS 1402 (Introduction to Social Psychology) and SS 1301 (U.S. Government). SS 1402 (Introduction to Social Psychology) is also a good alternative preparation for SS 2207 (Science and Creativity).

The two-course sequence, SS 1202 (Sociological Concepts) and SS 3278 (Technology Assessment and Impact Analysis Seminar), is also a fine approach to take if someone is interested specifically in Social Impact Analysis. Those interested in extending SS 1202 (Sociological Concepts) and SS 2208 (Society-Technology Debate) with more work on a related theme should consider taking SS 3278 (Impact and Assessment Seminar) or SS 2302 (Science - Technology Policy).

POLITICAL SCIENCE/PUBLIC POLICY

Three courses introduce students to the analysis of public policy: SS 1301, U.S. Government; SS 1303, American Public Policy; and either SS 2302, Science-Technology Policy, or SS 2304, Governmental Decision Making and Administrative Law. This sequence is designed for students who want to obtain an understanding of American government, its institutions, and the factors affecting public policy. The courses would be especially useful for students whose IQPs will address a public policy issue or some problem that requires a response from government. In addition, the courses will impart an appreciation for our political heritage and the values, which shaped our constitutional structure.

The political environment for science and technology has become extremely complex during the last few decades. Government directly supports over half of the nation's research and development. It also regulates the use of many technologies, including nuclear power, biotechnology, and manufacturing processes, which potentially harm the environment. Moreover, scientists and engineers are frequently called upon to help government solve problems. They often find themselves uncomfortably in the midst of political controversies.

These courses would shed some light on the mysterious processes of government. By enabling students to critically assess the performance of government and to articulate their own policy preferences, the courses would eliminate one barrier preventing WPI students from contributing to the public process.

CURRICULUM GUIDELINES FOR SYSTEM DYNAMICS

Recommendations for complying with the program distribution requirements (10 units) are described below. To earn a Bachelor of Science (B.S.) degree in System Dynamics, students must complete 15 units of coursework. In addition to the requirements below, one must complete the Sufficiency (2 units), the Interactive Qualifying Project (1 unit), free electives (5/3), and physical education (1/3).

Specific course recommendations for complying with the program distribution requirements are given below. These recommendations are intended to offer flexibility while preparing students for careers in system dynamics.

System Dynamics (5/3)

Students can choose from among the following 6 courses in system dynamics:

SS 1510	Introduction to System Dynamics Modeling
SS 1520	System Dynamics Modeling
SS 1503	The Psychology of Decision Making and Problem Solving
SS 2530	Advanced Topics in System Dynamics Modeling
SS 2540	Group Model Building
SS 3550	System Dynamics Seminar

Other Social Science (5/3)

It is recommended that the requirement for microeconomics or macroeconomics be satisfied with either SS 1110 or SS 1120, although higher level economics courses are also possible. It is recommended that the requirement for cognitive or social psychology be satisfied with SS 1401 or SS 1402, although higher level psychology courses are also possible. The public policy requirement can be met by taking one of the following courses: SS 1301, SS 1303, SS 2302, SS 2304, SS 2312. The other two social science courses are free electives and students can take any additional four courses in economics, sociology, political science and law, psychology, and system dynamics.

Management (2/3)

The requirement for organizational science may be met by taking one of MG/IE 2300 or MG/IE 3351. The second management course is a free elective.

Mathematics and Basic/Engineering Science (8/3)

The requirement for differential and integral calculus may be met by completing the calculus sequence through MA 1024. Higher level math courses or other basic science or engineering courses may be substituted if students complete MA 1024 without taking the full sequence MA 1021-MA 1024. It is recommended that the requirement for differential equations be met by MA 2051 and the requirement for numerical analysis be met by MA 3457/CS 4033, and the requirement for statistical analysis by MA 2611 or SS 2130. Once the math requirements are met, students may take any combination of additional math, basic science, or engineering courses to complete the 8/3 unit requirement. Those pursuing computer science as an application area should take CS 2022 to be able to follow upper level courses in the application area. It is recommended, but not required, that students take PH 1110 and PH 1120 as preparation for ES 3011.

Computer Science (2/3)

CS 1005 and CS 2005 are recommended.

Application Area (5/3)

A minimum of 5/3 units of integrated coursework is required to satisfy this requirement. Often students focus their applied courses in a particular area such as those noted below. Other focus areas are possible but must be approved by the student's academic advisor and the Department's Undergraduate Committee early in the student's program. Suggested courses for 12 application areas are given below. There is some flexibility needed in the selection of these courses since system dynamics covers a wide range of policy agenda. The student must take 3 additional courses to get a minor in an application area. Requirements of the respective departments are to be met in the course selection for the minors.

Economics

Select 3

SS 1110 Introductory Microeconomics
SS 1120 Introductory Macroeconomics
SS 2110 Intermediate Microeconomics
SS 2120 Intermediate Macroeconomics

Select 2

SS 2117 Environmental Economics
SS 2125 Development Economics
MG/IE 2850 Engineering Economics

Project Dynamics

Required

CE 1030 Civil Engineering and Computer Fundamentals

Select 3

MG 2101 Management Accounting
CE 3020 Project Management
CE 3021 Cost Estimating, Scheduling and Control
CE 3022 Legal Aspects in Design and Construction
MG 2200 Financial Management
SS/CE 4000 Independent Studies in Project Management

Engineering Systems

Required

ME 1800 Materials Selection and Manufacturing Process

Select 4

ME 3311 Dynamics of Mechanisms and Machines
ME 3321 Dynamic Modeling
ME 3422 Environmental Issues and Analysis
ME 3820 Computer-Aided Manufacturing
MG/IE 3400 Production System Design
MG/IE 3440 Information Systems Management
MG 3700 Information Systems Management

Public Policy

Select 2

SS 1301 US Government
SS 1303 American Public Policy
SS 1310 Law Courts and Politics
SS 1320 Topics in International Politics

Select 3

SS 2117 Environmental Economics
SS 2125 Development Economics
SS 2302 Science-Technology Policy
SS 2304 Government Decision Making and Administrative Law
SS 2311 Legal Regulation of Environment
SS 2312 International Environmental Policy

Fire Protection Engineering

Required

FP 3070 Fundamentals of Fire Safety Analysis

Select 4

MG/IE 3501 Management Science II: Risk Analysis
Any other course and Independent Studies in Fire Protection Engineering

Environmental Policy

Select 2

BB 2040 Principles of Ecology
CE 3059 Environmental Engineering
CE 3070 Urban and Environmental Planning
CE 3074 Environmental Analysis
CM 3910 Chemical and Environmental Technology
CM 3920 Air Quality Management
ME 3422 Environmental Issues and Analysis

Select 3

PY 2717 Philosophy and Environment
SS 2117 Environmental Economics
SS 2125 Development Economics
SS 2311 Legal Regulation of Environment
SS 2312 International Environmental Policy
SS 2405 The Psychological Study of Environmental Issues

Computer Science

Select 4 or more

CS 2223 Algorithms
CS 3041 Human Computer Interaction
CS 3431 Database Systems I
CS 3733 Software Engineering
CS 4241 Webware: Network Information Systems
CS 4341 Intro to Artificial Intelligence
Any other course and Independent Studies in Computer Science

Select 1 or more

MA 2210 Mathematical Methods in Decision Making
MA 3457 Numerical Methods for Calculus and Differential Equations
MA 4411 Numerical Solutions to Differential Equations

Infrastructure Planning

Select 2

SS 1120 Introductory Macroeconomics
SS 2120 Intermediate Macroeconomics
SS 2125 Development Economics
CE 1030 Civil Engineering and Computer Fundamentals

Select 3

CE 3020 Project Management
CE 3021 Cost Estimating, Scheduling and Project Control
CE 3022 Legal Aspects in Design and Construction
CE 3070 Urban and Environmental Planning
CE 4024 Real Estate Development

Society-Technology Studies

Select 5

SS 1202 Sociological Concepts and Comparative Analysis
SS 1402 Introduction to Social Psychology
SS 2208 The Society - Technology Debate
SS 2302 Science-Technology Policy
SS 3278 Technology Assessment and Impact Analysis Seminar
CS 3043 Social Implications of Information Processing
HI 2333 History of Science from 1700
HI 3331 Topics in Science, Technology and Society

Transportation Planning

Select 3

CE 3050 Highway Engineering and Planning
CE 3051 Transportation Systems
CE 3070 Urban and Environmental Planning
CE 3074 Environmental Analysis
CE 4071 Land Use Development and Controls
CE 3020 Project Management

Select 2

SS 1110 Introductory Microeconomics
SS 1120 Introductory Macroeconomics
SS 2110 Intermediate Microeconomics
SS 2117 Environmental Economics
SS 2120 Intermediate Macroeconomics
SS 2125 Development Economics

Electrical Power Systems Planning
Select 2
SS 1110 Introductory Microeconomics
SS 1120 Introductory Macroeconomics
SS 2110 Intermediate Microeconomics
SS 2120 Intermediate Macroeconomics
Select 3
EE 3601 Principles of Electrical Engineering
EE 4502 Analysis of Large Scale Electric Power Systems
CE 3070 Urban and Environmental Planning
Independent Studies on Electrical Power Systems Planning

Model Analysis
Select 5
ES 3011 Control Engineering I
MA 2210 Mathematical Methods in Decision Making
MA 3457 Numerical Methods for Calculus and Differential Equations
MA 4411 Numerical Analysis of Differential Equations
Independent studies in model analysis

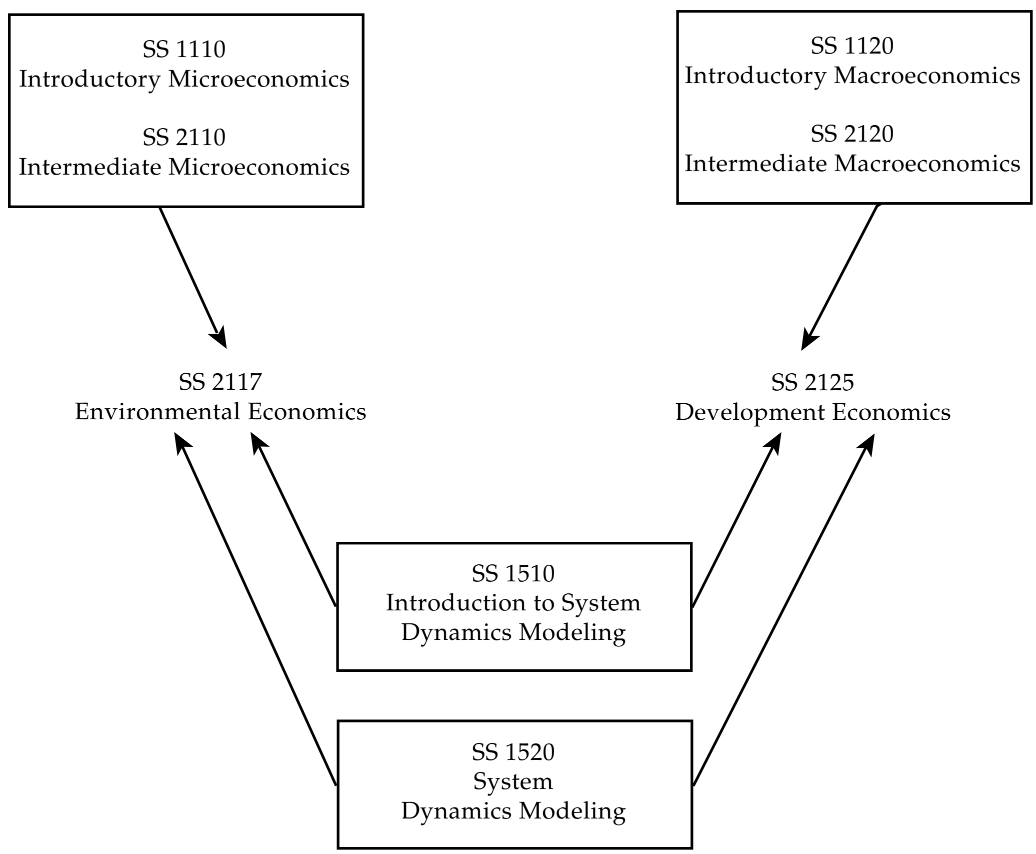
Major Qualifying Project (3/3)

The MQP is expected to provide an integrative capstone experience in system dynamics. Students must complete an MQP that applies system dynamics modeling or methodology to the student's chosen application area.

DOUBLE MAJOR IN SOCIAL SCIENCE AND POLICY STUDIES

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

SOCIAL SCIENCE AND POLICY STUDIES—COURSE SEQUENCE CHART



SOCIAL SCIENCE MINORS

A Social Science Minor is available in any of the following disciplines:
Economics
Sociology
Political Science and Law
Psychology
System Dynamics
Social Science

A minor in the Social Sciences consists of 2 units of academic activity satisfying the following conditions:

1. Foundations

Introductory level courses in any one or two social science disciplines taught at WPI: economics, sociology, political science (and law), psychology, and system dynamics. 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 disciplines as the foundation courses, which involve applications or extensions of the material covered in the introductory courses and lis the introductory courses as reccommended background. High level courses have either a 2, 3, or 4 as the first digit of the course number.

The capstone experience will consist of a paper in the last applied course taken. The paper must draw upon and integrate material covered in the previous courses. An IQP may provide the capstone experience and substitute for the last applied course provided that the IQP was advised or co-advised by a member of the Social Science & Policy Studies department, and contains appropriate social science analysis.

3. If five or more of the six 1/3 units required for the minor are in a single social science discipline, the title of the minor will be "Minor" in that discipline.* Otherwise the title of the minor wil be "Minor in Social Science." Examples of minor programs in economics, sociology, political science (and law), psychology, system dynamics and interdisciplinary social science are available at the SS & PS department office. The course selected for an interdisciplinary social science minor should follow an identifiable theme, such as the relationship between technology and society or social, political, economic or environmental policies.

Students taking minors in the social sciences are expected to designate a member of the SS & PS department as their SS minor advisor, who will assist them in preparing a program that meets the requirements of the minor. Students can obtain assistance at the SS & PS departmental office in designating an advisor.

Students completing any major in the Social Science and Policy Studies Department may not also complete a minor in social sciences.

* In designating sociology the minor, the course SS 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:
SS 1110–Introductory Microeconomics;
SS 1120–Introductory Macroeconomics;
SS 2210–Intermediate Microeconomics; and
SS 2120–Intermediate Macroeconomics.