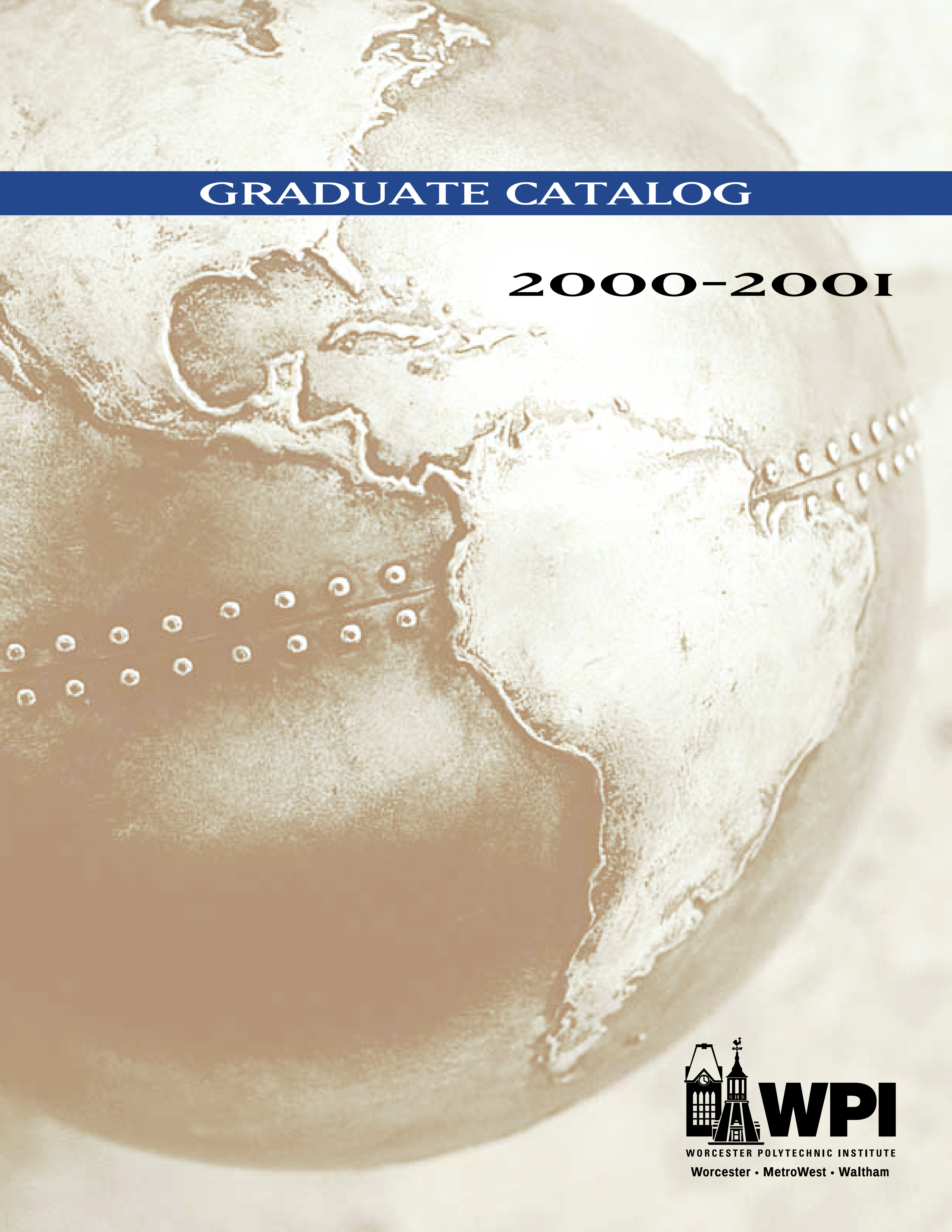
2000

Graduate Catalog 2000-01

Worcester Polytechnic Institute



GRADUATE CATALOG

2000-2001

WPI

WORCESTER POLYTECHNIC INSTITUTE

Worcester • MetroWest • Waltham

INFORMATION SESSIONS

To discuss graduate opportunities at WPI in greater detail or to request a catalog, application or registration materials, please contact the following at WPI:

Graduate Admissions Office
100 Institute Road
Worcester, MA 01609
508-831-5301 (V)
508-831-5717 (F)
gao@wpi.edu (E)

Waltham Campus
Graduate Admissions Office
60 Hickory Drive
Waltham, MA 02451-1012
800-WPI-9717 (V)
781-466-8499 (F)
waltham@wpi.edu (E)

http://www.wpi.edu/Admin/GAO

Courses in the following disciplines are available at these WPI locations this year.

Worcester:
All programs

MetroWest:
Computer Science;
Electrical and Computer Engineering

Waltham:
Computer Science;
Electrical and Computer Engineering;
Management

Worcester

100 Institute Road
All Programs

Wednesday, July 12
Highway Infrastructure Program
Department of Civil & Environmental Engineering
Higgins House, 6 p.m.

Wednesday, August 23
Higgins House, 6 p.m.

Thursday, November 16
Higgins House, 6 p.m.

Wednesday, January 10, 2001
Higgins House, 6 p.m.

Thursday, May 3, 2001
Higgins House, 6 p.m.

Waltham

60 Hickory Drive
Computer Science, Electrical & Computer Engineering, Management Programs

Thursday, August 24
Waltham Campus, 6 p.m.

Tuesday, September, 19*
Waltham Campus, 6 p.m.

Tuesday, October 17*
Waltham Campus, 6 p.m.

Wednesday, December 6
Waltham Campus, 6 p.m.

Thursday, January 11, 2001
Waltham Campus, 6 p.m.

Wednesday, March 20, 2001*
Waltham Campus, 6 p.m.

Wednesday, May 9, 2001
Waltham Campus, 6 p.m.

** Management only*

MetroWest

225 Turnpike Road, Southborough
Computer Science, Electrical & Computer Engineering Programs

Thursday, August 17
MetroWest Campus, 6 p.m.

Tuesday, January 9, 2001
MetroWest Campus, 6 p.m.

To ensure that a representative is available to speak with you, you must register for the information session and specify the areas of study in which you are interested - call 800-WPI-9717, or fill out the **online registration form** to reserve your space!

Welcome to WPI

WPI is a doctoral university offering graduate education and research opportunities in engineering, management, and science. Founded in 1865 as an undergraduate school, WPI has become a leader in graduate research and education, awarding its first graduate degree in 1893. As the third oldest private technological university in the United States, WPI has much to offer by way of scholarship, history and community leadership. The faculty and student body are comprised of some of the world's brightest and most talented individuals who bring diversity and excitement to the learning process.

With approximately 1,100 graduate students, WPI can offer individual attention in its classrooms and laboratories; students and faculty have opportunities to work collaboratively and inter-actively. Through its commitment to provide diverse and global opportunities, students have unique opportunities to study with renowned educators, utilize state of the art laboratories, and create new knowledge and tools that will become part of the future.

For those who endeavor to pursue a life of scholarship in academia and whose credentials are at the highest levels, WPI offers teaching assistantships, research assistantships and many fully funded fellowships, which are provided through endowed funds of our founders, alumni, corporations and community philanthropists. Our masters programs focus on working professionals who want to advance their academic careers in technical or management fields. And, our doctoral programs focus on research at the frontiers of knowledge and training for teaching and research.

Flexibility and convenience are fundamental components of our programs. Students have the option to design independent and interdisciplinary programs of study, on a full or part time basis. For full-time working professionals, graduate certificate and masters degree programs are available during twilight and evening hours at one of three conveniently located campuses in the heart of New England or on the east coast of Massachusetts: in Worcester, MetroWest and Waltham. Finally, through our advanced distance learning network (ADLN), many courses are available in the virtual environment, either via videotapes, satellite or the WEB, providing the maximum in convenience.

WPI takes pride in offering first rate graduate and research programs. I invite you to read this catalog, talk with our admissions staff and faculty and visit our campuses. I am confident that you will find WPI to be a university at which you will have every opportunity to achieve your goals for advanced study and career development.

Sincerely,

Dr. Edward Alton Parrish
President, Worcester Polytechnic Institute

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The University and the Community

Graduate Study at WPI

WPI, the nation's third oldest technological university, was also among the first to recognize the need to provide engineering, technical and management professionals with graduate-level educational opportunities on a part- and full-time basis.

Opportunities for graduate study at the university range from formal graduate degree programs, to graduate certificates, to advanced study for non-degree students, to off-campus study through WPI's Advanced Distance Learning Network, which brings graduate education to the workplace or home. Part-time graduate students at WPI benefit from the same personalized faculty advising as our full-time students.

WPI addresses the requirements of full-time students, technically oriented professionals and secondary school educators with a wide range of advanced courses and programs with flexibility, quality and optimal accessibility. For added convenience, many programs are offered at one or more of our three campuses in central and eastern Massachusetts or through our Advance Distance Learning Network.

History

WPI was founded in 1865 as the Worcester County Free Institute of Industrial Science, primarily through the efforts of John Boynton, a prosperous tinware manufacturer from the nearby town of Templeton, Mass. It was the merger of Boynton's vision with that of Ichabod Washburn, the community's leading industrialist, that resulted in what was then a unique educational program, one that combined scientific and technical studies with practical work in a model industrial shop.

WPI awarded its first master of science degree, in electrical engineering, in 1893. Its first doctoral degree, in natural science, was granted in 1904. New programs have been added regularly in response to the growing capabilities of the university and the changing needs of the professions.

Currently, WPI offers master's degree programs in 30 disciplines and doctoral programs in 23 disciplines.

More than 40 years ago, responding to the demanding work schedules of professionals, WPI developed the first of what is today an extensive array of part-time graduate programs. Each is designed to accommodate the professional development needs of those with significant career and family commitments.

The current student body of 3,600 includes more than 400 full-time and more than 600 part-time and non-degree graduate students. They are taught by about 200 tenure-track and 100 part-time and non-tenure-track faculty members.

Locations

WPI is set on a 80-acre hilltop campus situated in a residential section of Worcester, MA, a city of 170,000. Located in the heart of New England, Worcester is the second largest city in the six-state region.

Worcester is well known for its many colleges and for such cultural landmarks as the Worcester Art Museum, which houses one of the finest collections in the country, and the world-renowned American Antiquarian Society, both of which are adjacent to WPI. Also nearby are the historic Higgins Armory Museum and the New England Science Center. Music is well-represented by several excellent choruses, a symphony orchestra, and concerts performed by internationally recognized artists in the beautifully restored Mechanics Hall, one of the finest concert halls in the U.S. The city is also home to several professional and amateur theater companies. The 15,500-seat Worcester Centrum Centre hosts a wide variety of entertainment and athletic events and meetings.

Central to New England, the city is within an easy drive of many historical sites, cultural centers and recreational facilities. These include Boston's Freedom Trail, Old Sturbridge Village (a living museum depicting 1830 rural village life), Fenway Park, the beaches of Cape Cod and Maine, the ski slopes of New Hampshire and Vermont, the splendid country charm of the Berkshires, and several major metropolitan areas featuring world-class museums, concert halls and professional sports teams.

The Academic Calendar

The graduate academic calendar is divided into fall, spring, and summer semesters. The undergraduate academic calendar is divided into seven-week terms; the fall semester terms, A and B, the spring semester terms, C and D. Term E is the summer semester. Details of the WPI academic calendar, including dates on which graduate classes begin and end for each semester appear below.

2000

August 17
Teaching Assistants report to campus

August 18+19
Teaching and Research Assistant Orientation

August 30, 31, Sept. 1, Sept. 5
Walk-in Registration for fall semester courses

August 31
First day of classes, Term A
(undergraduates)

September 5
Fall semester graduate classes begin

October 19
Last day of classes, Term A
(undergraduates)

October 30
First day of classes, Term B
(undergraduates)

November 1
Deadline for filing Application for Graduation for February 2001

November 21-26
Thanksgiving recess

December 15
Fall semester end

December 19
B Term classes end
(undergraduates)

2001

January 10-15
Walk-in Registration for spring semester courses

January 11
First day of classes, Term C
(undergraduates)

January 15
Spring semester graduate classes begin

February 12
Deadline for filing Application for Graduation for May 2000

March 1
Last day of classes, Term C
(undergraduates)

March 13
First day of classes, Term D

April 27
Spring semester graduate classes end

May 1
Last day of classes, Term D
(undergraduates)

May 19
Spring 2001 Commencement

May 24-May 31
Walk-in Registration for summer session classes

May 31
Summer session classes begin

June 4
Deadline for filing Application for Graduation for October 2000

July 19
Last day of classes, graduate summer short (7-week) courses

August 9
Last day of classes, graduate summer long (10-week) courses

GRADUATE DEGREE PROGRAMS

WPI offers graduate study leading to the master of science, master of engineering, master of mathematics for educators, master of business administration, and the doctor of philosophy degrees. Please see chart on page 10 for details.

Master of science degree programs are available, on a full-time and part-time basis, in the following disciplines:
- applied mathematics
- applied statistics
- biomedical/clinical engineering
- chemistry and biochemistry
- civil and environmental engineering
- computer science
- electrical and computer engineering
- fire protection engineering
- management
- manufacturing engineering
- materials science and engineering
- mathematical sciences
- mechanical engineering
- physics

Master's programs in biology, biotechnology and chemical engineering are available only on a full-time basis.

Master of engineering programs are offered in:
- biomedical/clinical engineering
- civil and environmental engineering
- manufacturing engineering
- mechanical engineering

Master of Business Administration (M.B.A.) programs provide students with strategies for the successful application of technology to complex business environments. The degree requirements are described in this catalog and in a separate brochure available from the Management Department at 508-831-5218.

Master of Mathematics for Educators
In response to the national need to prepare junior and senior high school students with imaginative mathematics teaching, WPI offers a specific part-time graduate program, the master of mathematics for educators, for teachers of mathematics. This program allows junior high, high school and community college teachers an opportunity to obtain a master's degree in a content-based program at a time convenient to practicing teachers. Taught by professors of mathematics at WPI, the program is designed to permit the teachers to learn from professors' research interests and includes an understanding of current developments in the field. Scholarship aid, which covers approximately 40 percent of the cost of tuition, is available to qualified participants.

The number of courses offered each year may be limited in some disciplines; however, the schedule of courses over a period of time generally allows a student taking three or four courses per semester to complete the course requirements in about two years. Students taking two courses per semester complete the course requirements for the master of science or engineering degrees in about three years, or the master of business administration degree in about four years.

Questions relating to these programs should be referred to the discipline department heads or the Graduate Admissions Office.

The doctor of philosophy (Ph.D.) is available in biomedical science and all of the disciplines outlined previously except management and mathematics for educators.

Interdisciplinary Doctoral Programs
New fields of research and study that combine traditional fields in innovative ways are constantly evolving. In response to this, WPI encourages formation of interdisciplinary doctoral programs to meet new professional needs or the special interests of particular students. Such programs are initiated by groups of at least three full-time faculty members who share a common interest in a cross-disciplinary field. A sponsoring group submits to the Committee on Graduate Studies and Research a proposal for an interdisciplinary degree, together with the details of a program of study and the credentials of the members of the group. At least one member of the group must be from a department or program currently authorized toward the doctorate.

If the CGSR approves the proposal, the sponsoring group serves in place of a department in establishing specific degree requirements beyond those of the Institute, in advising, in preparing and conducting examinations, and in certifying fulfillment of degree requirements.

WPI and Clark University pioneered in developing a graduate biomedical engineering program, jointly administered by the two institutions. More recently, WPI, Clark, the University of Massachusetts Medical School and the Worcester Foundation for Biomedical Research have joined to offer a doctoral program in research in biomedical science.

GRADUATE AND ADVANCED CERTIFICATE PROGRAMS

Keeping pace with technological advancement today is a full-time job. At WPI, our innovative graduate level certificate programs are uniquely equipped to help you update your understanding with new concepts and insights, without a major commitment of time and money. WPI offers two certificate program options for individuals wishing to pursue graduate course work, with the benefit of academic advising and without committing to a full degree program, the Graduate Certificate and the Advanced Certificate. Upon completion of the required course work, students are awarded a Certificate of Graduate Study or a Certificate of Advanced Graduate Study in their particular program of study (e.g., Certificate of Graduate Study in Management with a specialization in Information Technology). Course credits may be applied to a graduate degree if the student is admitted to a degree program at a later date.

Graduate Certificate Program

The Graduate Certificate Program (GCP) at WPI provides an opportunity for students holding undergraduate degrees to continue their study in an advanced area. A B.S. or B.A. degree is the general requirement. However, some departments look for specific backgrounds when making admission decisions. This program requires students to complete four to six thematically related courses in their area of interest. Each student's program of study must be approved by the academic advisor.

Biomedical/Clinical Engineering
(Undergraduate degree in engineering or science preferred.)
- Medical Instrumentation and Devices

Civil and Environmental Engineering
(Undergraduate degree in civil engineering or another acceptable field preferred.)

- Construction Project Management
- Environmental Engineering
- Master Builder
- Materials/Transportation
- Structural Engineering

Computer Science
(Undergraduate degree in computer science or computer engineering preferred; students with other backgrounds may need to take CS 507 or CS 501 as bridge courses into the program.)

- Artificial Intelligence
- Computer and Communications Networks
- Computer Systems
- Database Design
- Graphics/Image Processing/Visualization
- Programming Languages
- Software Engineering and Interface Design

Electrical and Computer Engineering
(Undergraduate degree in electrical or computer engineering preferred.)

- Computational Fields
- Computer Systems
- Computer and Communications Networks

Fire Protection Engineering
(Undergraduate degree in science or engineering preferred.)

Mathematical Sciences
(Knowledge of differential equations equivalent to that provided by an introductory college course required for the Industrial Mathematics Certificate Program; knowledge of statistics equivalent to that provided by an introductory college statistics course required for the Industrial Statistics Certificate Program.)

- Industrial Mathematics
- Industrial Statistics

Management
(Undergraduate degree in science, engineering or management preferred; individuals holding bachelor's degree in other disciplines with relevant work experience also considered.)

- Information Technology
- Technology Marketing
- Management of Technology
- Customized Certificate of Management

Manufacturing Engineering
(Undergraduate degree in engineering, mathematics or computer science preferred.)

Materials Science and Engineering
(Undergraduate degree in engineering, chemistry, physics or mathematics preferred.)

Additional concentrations may be developed in consultation with an academic advisor.

Advanced Certificate Program

The Advanced Certificate Program (ACP) provides master's degree holders with an opportunity to continue their studies in advanced topics in the disciplines in which they hold their graduate degree or that are closely related to their master's degree fields. The program consists of a set of five courses—none of which were included in the student's formal master's program of study. The courses may include either a depth or a breadth option. Each participating department identifies one or more guideline programs; however, each student's program of study may be customized to satisfy a student's unique needs. The program of study is reviewed and approved by an academic advisor who is assigned upon the student's acceptance to the program.

Individuals may also apply for program admission to departments closely related to their master's degree fields. The departmental graduate committee will review such applications on a case-by-case basis to determine the applicant's eligibility. Individuals applying under this scenario would follow the same admission procedures as individuals applying who do not hold a WPI master's degree. Advanced Certificates, with just a few areas of possible specialization listed, are available in:

Civil and Environmental Engineering
- Waste Minimization and Management
- Building Regulatory Integration in Construction Management
- Computer Based Support Systems for Construction Management

Computer Science
- Advanced Computer Systems
- Advanced Computer Science
- Artificial Intelligence Data and Knowledge
- Data and Knowledge Based Systems
- Compilers and Languages
- Image Science

Electrical and Computer Engineering
- Computational Fields
- Computer and Communications Networks
- Advanced Computer Systems

Fire Protection Engineering
Mechanical Engineering
- Computational Mechanics
- Fluid Mechanics
- Stress Analysis
- Vibrations and Controls
- Manufacturing Engineering
- Materials Science and Engineering

Additional specializations may be developed in consultation with an academic advisor.

Application Process

The application to these programs requires submitting to the Graduate Admissions Office an official application form, official copies of transcripts for all college course work completed, and a $50 application fee (waived for WPI alumni). Management certificate applicants must also submit three letters of recommendation and GMAT/GRE scores. International students may apply to these programs. However, for WPI to issue the required student visa, international students must be registered for a minimum of 9 credits during their first semester and must complete their program within one academic year.

Registration Procedures

Graduate and Advanced Certificate Program students register with WPI's evening graduate students, follow the same registration procedures, and participate in the same classes as all other graduate students.

Tuition and Fees

Tuition and fees for GCP and ACP students are the same as for all other WPI graduate students on a per-credit hour basis. Tuition for 2000-2001 Academic Year is $703 per credit hour.

Academic Policies

Academic policies follow the same guidelines as those established for degree seeking graduate students, with the following exception: If after completing 9 credits, a certificate program student's grade point average falls below 2.5, he/she will be withdrawn from the program unless the academic department intervenes.

Program Planning

Students will be assigned faculty advisors and will be required to complete a Plan of Study. The Plan of Study must be approved and signed by the academic advisor before the end of the student's first semester in the program. Copies of the plan will be maintained by the student, the academic advisor and the department. Students may initiate written requests to the advisor, via the Program Modification Form, to modify the program of study. Copies of approved program modification(s) should be retained by the student, the academic advisor and the department.

Completion Time Limit

Certificate program students will have four years from the date of matriculation to complete the program. International students may apply to these programs. However, for WPI to issue the required student visa, international students must be registered for a minimum of 9 credits during their first semester and must complete their program within one academic year.

Transfer of Credits

Up to 6 credits of course work taken at WPI may be transferred into the program. Students who wish to apply credits earned in the GCP or the ACP to a subsequent master's or Ph.D. program at WPI must make formal application to the degree-granting department. Admission to the GCP or ACP does not guarantee admission to any subsequent WPI degree-granting program.

Program Completion

Satisfactory completion requires a cumulative quality point average of 3.0 or better (A=4.0) with grades of C or better in all courses completed in the program. Upon satisfactory completion of the program, students will receive a Certificate of Graduate Study or Advanced Graduate Study in the chosen discipline. Should students later apply to the M.S. degree or Ph.D. program, and be accepted, the GCP and ACP courses will be considered for transfer toward the degree requirements.

COMBINED BACHELOR'S/ MASTER'S PROGRAM

The Combined Bachelor's/Master's Program is a unitary program leading a student to a bachelor of science degree and to a master of business administration, master of engineering, or master of science degree. The purpose of the Combined Bachelor's/Master's Program is to give WPI undergraduates an opportunity to earn a bachelor's and a master's degree from WPI concurrently in less time than would be required if the student were to complete work on the bachelor's degree before beginning work on the master's degree. To gain the full benefit of this program, a student should apply for the Combined Program well before the bachelor's degree is completed. **Application at the beginning of the junior year is recommended.**

For the master of science and master of engineering degrees, the Combined Program typically allows a student to complete requirements for both degrees in about one more year of full-time study than would be required to earn the bachelor's degree. With careful planning, a student can obtain a similar reduction in the amount of time required to earn an M.B.A. Undergraduate students may apply up to 4 courses to the master's degree, with prior written approval from professors and the academic department. The M.S. portion of the program must be completed as a full-time student.

ADVANCED STUDY FOR NON-DEGREE STUDENTS

For those who do not want to commit themselves to a degree program but who wish to enroll in a single course or a limited number of courses in a specialized field, WPI provides the opportunity to participate in graduate level courses on an ad hoc basis. When registering for courses as a non-degree student, grading may be either conventional (A,B,C) or Pass/Fail. Pass/Fail grading must be elected at the time of registration, and courses taken on the Pass/ Fail basis are not transferable to any master's degree program. The maximum number of courses that may be taken as a non-degree student is four with the following exceptions: 3 course maximum in Biomedical Engineering, Computer Science, and Electrical and Computer Engineering: 2 course maximum in Management.

INTERCOLLEGE STUDIES AND THE CONSORTIUM

The Colleges of Worcester Consortium was established in 1967. In the consortium, 20,000 students of eight four-year colleges with graduate programs, two two-year schools, a medical school and a veterinary school have access to all the educational benefits of these institutions as well as nine other specialized institutions in the area. The Consortium members and associates whose facilities and programs have been particularly useful to WPI graduate students are Assumption College, Clark University, College of the Holy Cross, Tufts School of Veterinary Medicine, University of Massachusetts Medical School, Worcester Foundation for Biomedical Research and Worcester State College. Cross-registration in courses and the use of special laboratory facilities are encouraged. The Consortium operates a free bus service for transporting students between the colleges. Schedule for services can be found in the Gordon Library.

NON-CREDIT CONTINUING PROFESSIONAL EDUCATION PROGRAMS

WPI offers a wide range of non-credit courses and certificate programs to help technical professionals and managers update their knowledge and skills

For more information on WPI's Non-Credit Continuing Professional Education Programs call the Continuing Education Office at 508-831-5517.

SCHOOL OF INDUSTRIAL MANAGEMENT

The connection between technology and business management has never been more powerful than it is today. Technological advances have changed the very nature of business by creating and eliminating markets, altering communication patterns, and setting new rules about the flow of information. The changes grow more dramatic each year.

SIM has the unique ability to combine technology based courses with management courses to offer customized certificate programs for industry. Drawing more than 50 years of experience, SIM offers challenging, technology-orientated business programs that give its graduates a distinct edge in the high-tech management marketplace.

SIM professors are experts in all aspects of technology management: running high-tech firms; converting technological innovations into commercial products, services and organizations; and integrating technology into existing organizations.

The School of Industrial Management (SIM), designed for students who are sponsored by their employers, offers a four-year curriculum that leads to a certificate of completion and advanced certificate option.

Call 508-831-5208 for more information.

GRADING SYSTEM/ ACADEMIC STANDARDS

Grading System

In order to assess progress throughout the graduate program, grades are assigned to the student's performance in course, project and thesis work. Academic achievement is based on the following grading system:

A	Excellent
B	Good
C	Pass
D	Unacceptable for graduate credit
F	Fail
AU	Audit
NC	No credit (only for thesis work); will not be recorded on transcript
P	Pass; unacceptable for graduate credit
I	Incomplete; transition grade only; becomes grade of F if not changed by instructor within 12 months
W	Withdrawal
SP	Satisfactory progress; continuing registration in thesis/dissertation/ directed research
CR	Credit for work at another institution
UP	Unsatisfactory progress; this grade remains on the file transcript

Academic Standards

Students must maintain high academic standards in all their program activities. After completion of 12 credit hours, all students must maintain an overall (QPA) grade point average above 2.75 to be considered making satisfactory progress.

If a student's overall QPA falls to 2.75 or below, the student and advisor are notified by the registrar that the student is not making satisfactory progress.

If the overall QPA of any student falls below 2.65, the registrar will inform the student that all future registrations will be given grades only on a pass/fail basis unless the department graduate committee intervenes.

If the overall QPA of any student falls below 2.5, the student is removed from the program unless the department graduate committee intervenes.

Quality Point Average

Grades are assigned the following quality points: A = 4.0, B = 3.0, C = 2.0, D = 1.0 and F = 0.0. The Quality Point Average (QPA) is calculated as the sum of the products of the quality points and credit hours for each registered activity (including courses, independent studies, directed research, thesis research and dissertation research) in the average, divided by the total number of credit hours for all registered activities in the average. If a student takes the same course more than once, the course enters the QPA only once, the most recent grade received for the course being used in the average.

A student's overall QPA is calculated on the basis of all registered activities taken while enrolled as a graduate student at WPI. WPI graduate courses taken before a student had status as a degree-seeking graduate student are included in the overall QPA. A student's program QPA is calculated on the basis of those WPI courses listed by the student on the student's Application for Graduation form. The transcript will report the overall QPA.

Courses transferred from elsewhere for graduate credit (for which a grade of CR is recorded on the WPI transcript), and courses taken to satisfy undergraduate degree requirements or to remove deficiencies in undergraduate preparation, are not included in either QPA. Registered activities in which the student receives grades of AU, NC, P, I, W, SP or UP are not included in either QPA.

Only registered activities in which a grade of A, B, C or CR was obtained may be used to satisfy courses or credit requirements for a graduate degree.

Changing of Grades

Once a course is completed, a student wishing to change a grade to withdraw, change an audit to a grade, or change a grade to an audit must petition the Committee on Graduate Studies and Research (CGSR) to affect the change. The petition must include the instructor's approval. Only under exceptional circumstances will such requests be approved.

Advising/Plan of Study

Newly admitted students will be advised of available courses that will be acceptable to their Program of Study prior to registration to encourage and facilitate preregistration.

Newly admitted full-time graduate students will be assigned an academic advisor at the time they are accepted and pay a tuition deposit. Part-time graduate students will be assigned an advisor at the time of their admission to degree-seeking status.

After consultation with and approval by the advisor, each admitted student must file a formal Plan of Study with the department within the first semester if full-time, and within the first year if part-time. Program changes are implemented by advisor and student. Copies of the revised Plan of Study will be maintained in department files.

Three years after the initial filing of the plan of study and in three year intervals thereafter, a revised Plan of Study must be filed with the Projects and Registrar's Office prior to registration for additional academic credit. The plan of study must reflect all current courses that will be applicable towards the student's degree. Courses that are no longer current must be removed from the Plan of Study. The department will determine which courses are current.

INDEX OF GRADUATE PROGRAMS BY PROGRAM TYPE

Master of Business Administration
Master of Engineering
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Master of Science
Ph.D.
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Graduate Certificate
Advanced Graduate Certificate

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Biology and Biotechnology

Master of Science in Biology
Master of Science in Biotechnology
Ph.D. in Biology
Ph.D. in Biotechnology

Biomedical and Clinical Engineering

Master of Science in Biomedical Engineering
Master of Engineering in Biomedical Engineering
Master of Engineering in Clinical Engineering
Ph.D. in Biomedical Engineering
Graduate Certificate

Biomedical Science

Ph.D. in Biomedical Sciences

Chemical Engineering

Master of Science in Chemical Engineering
Ph.D. in Chemical Engineering

Chemistry and Biochemistry

Master of Science in Chemistry
Master of Science in Biochemistry
Ph.D. in Chemistry

Civil and Environmental Engineering

Master of Science in Civil Engineering
Master of Science in Environmental Engineering
Master of Science in Construction Project Management
Master of Engineering in Master Builder Program
Ph.D. in Civil and Environmental Engineering
Graduate Certificate
Advanced Certificate

Computer Science

Master of Science in Computer Science
Master of Science in Computer Science - Specializing in Computer and Communications Networks (CCN)
Ph.D. in Computer Science
Graduate Certificate
Advanced Certificate

Electrical and Computer Engineering

Master of Science in Electrical and Computer Engineering
Master of Science in Electrical and Computer Engineering - Specializing in Computer and Communications Networks (CCN)
Ph.D. in Electrical and Computer Engineering
Graduate Certificate
Advanced Certificate

Fire Protection Engineering

Master of Science in Fire Protection Engineering
Ph.D. in Fire Protection Engineering
Graduate Certificate
Advanced Certificate

Management

Master of Business Administration (M.B.A.)
Master of Science in Marketing and Technological Innovation
Master of Science in Operations and Information Technology
Graduate Certificate

Manufacturing Engineering

Master of Science in Manufacturing Engineering
Master of Engineering in Manufacturing Engineering
Ph.D. in Manufacturing Engineering
Graduate Certificate

Materials Science and Engineering

Master of Science in Materials Science and Engineering
Ph.D. in Materials Science and Engineering
Graduate Certificate

Mathmatical Sciences

Master of Mathematics for Educators
Master of Science in Applied Mathematics
Master of Science in Applied Statistics
Ph.D. in Mathematical Sciences
Graduate Certificate

Mechanical Engineering

Master of Science in Mechanical Engineering
Master of Engineering in Mechanical Engineering
Ph.D. in Mechanical Engineering
Advanced Graduate Certificate

Physics

Master of Science in Physics
Ph.D. in Physics

APPLYING TO WPI

A complete chart of admission requirements to each program is on page 13. Please direct questions to Graduate Admission 508-831-5301 or gao@wpi.edu

Requirements for admission include submission of the following:

- Application for Admission to Graduate Study Preference give to fall applicants with complete files before February 1.
- Nonrefundable $50 application fee (waived for WPI alumni)
- Official college transcripts from all accredited degree-granting institutions attended
- Three letters of recommendation (and/or other references) from individuals who can comment on the qualifications relevant to the applicant's admission
- TOEFL (Test of English as a Foreign Language) scores must be submitted by all international applicants for whom English is not the first language (waived for foreign students presently attending a U.S. school). TOEFL scores are only valid for two years. Minimum score of 550 on the paper exam is required or 213 on the computer-based exam.
- Statement of Purpose is required for individuals applying to Biology and Biotechnology, Biomedical/Clinical Engineering, Computer Science, Electrical and Computer Engineering (Ph.D. only), and Fire Protection Engineering (applicants without FPE work experience only). This is a brief essay discussing background, interests, academic intent, and the reasons the applicant feels he/she would benefit from the program.
- GRE (Graduate Record Examination) and GMAT (Graduate Management Admissions Test) Requirements:

  Biology and Biotechnology
  Biomedical/Clinical Engineering
  Computer Science
  GRE General Test Required (for all applicants to the BB Dept.)

  Chemistry and Biochemistry
  GRE General and/or Subject Test Required

  Chemical Engineering, Manufacturing Engineering, and Materials Science & Engineering
  GRE General Test Required for foreign applicants. Recommended for others

  Electrical and Computer Engineering
  GRE General Test Required for foreign applicants and those applying for graduate fellowships

  Management
  GMAT Required for M.B.A.; M.S. applicants may substitute GRE for GMAT

  Mechanical Engineering
  Physics
  GRE General Test Strongly Recommended

  Civil and Environmental Engineering
  Fire Protection Engineering
  Mathematical Sciences
  GRE Not Required, however, submission of strong scores can improve an applicant's success in competing for financial aid

- Goddard Fellowship applicants are required to submit GRE or GMAT scores
- Incomplete applications are retained in the Graduate Admissions Office for one year
- To apply to WPI, write to the Graduate Admissions Office, WPI, 100 Institute Road, Worcester, MA 01609-2280, call 508.831.5301 or e-mail gao@wpi.edu. You may also apply online through our Web site at www.wpi.edu
- Applications for WPI's graduate science and engineering programs may be requested from the Graduate Admissions Office at 508-831-5301 or on-line at www.wpi.edu
- Graduate management applications should be requested directly from the Management Department at 508-831-5218 or at wpigmp@wpi.edu
- To learn more about admissions standards and policies, deadlines, fellowships, teaching assistantships and research assistantships, please contact the Graduate Admissions Office at 508-831-5301 or gao@wpi.edu
- For information on loan programs and copies of the forms contact WPI's Financial Aid Office at 508-831-5469

ADMISSION

Admission to the graduate program of any department is granted by that department via the Graduate Admissions Office. Admission to graduate interdisciplinary programs is granted by the Committee on Graduate Studies and Research.

Admission to a program generally entitles a student to work toward those degrees offered by the admitting program. A student who has not been admitted to a program may not earn a degree from that program.

Some programs, in admitting a student, determine the degree toward which the student may work. In such a case, an admitted student who wishes to work toward a different degree in the same program should consult the department head of the admitting program as to procedures and requirements to be followed. Typically, such cases involve students who have been admitted to a program leading to a master's degree and wish to continue toward a doctorate.

An admitted student who wishes to work toward a second degree offered by a different department or program must apply to that second program for admission.

Standard application procedures are followed except that no application fee is required for a second degree. Admission to the second program is not automatic, and is determined by the faculty of the second program, based on customary admissions standards.

A minimum TOEFL score of 550 is required of students admitted from non-English-speaking countries. This requirement may be waived in special cases by the departmental graduate committee.

Under some circumstances a student not yet admitted to a program may earn graduate credit toward the requirements for a graduate degree. The fact that a student has been allowed to register for courses and earn graduate credit from a program does not guarantee that the student, at a later date, will be admitted to that program. Students are therefore encouraged to apply for admission to a program at the earliest possible date.

The procedure for applying as a part-time degree-seeking student is the same as that for a full-time student.

Deferred Enrollment

An admitted student who wishes to defer enrollment must make such a request in writing to the Graduate Admissions Office, which will seek counsel from the department involved.

Probational Admission

If an applicant's undergraduate record is below the usual standards for admission, but there are mitigating circumstances, admission on probation may be granted. Such admission usually means that the student's performance will be reviewed at a specified time and a decision will be made about continuation in the graduate program.

Conditional Admission

Under some circumstances (usually where the background of the student is considered to be incomplete by the department or program), conditional admission may be granted. Conditional admission indicates that the student will receive regular admission status only after overcoming the specific deficiencies as outlined in the conditional admission letter sent to these prospective students by the Graduate Admissions Office. The conditionally admitted student will be instructed in this letter as to specific course deficiencies, required minimum grades expected to be attained in these classes, time over which deficiencies are to be completed, etc. Progress of the conditionally admitted student will be monitored by the student's department/program of study. Please consult departmental descriptions for more details.

Transfers and Waivers

A student may petition for permission to use graduate courses taken at other institutions to satisfy WPI graduate degree requirements. A maximum of one-third of the credit requirements for a graduate degree may be satisfied by courses taken elsewhere. Petitions are subject to approval by the student's degree-granting program (which administratively may be a department or a program), and are then filed with the registrar. To ensure that work constitutes current practice in the field, the program may set a latest date at which each course may be applied toward the degree. Such courses are recorded on the student's WPI transcript with the grade CR, and are not included in calculations of quality point averages. Grades earned in biomedical consortium course work are recorded on the transcript as if the courses were taken on campus.

Applicants may file petitions with their application for admission to a WPI program. If the department admits the student and approves the petition, notice of the approval may be included in the Institute's letter of admission to the student. This inclusion is known as Admission with Advanced Standing.

A student with one or more WPI master's degrees, who is seeking a further master's degree from WPI, may petition to apply up to 9 credits used to obtain the previous WPI degrees toward satisfying requirements for the degree presently being sought.

A student who withdraws from a graduate program and is later readmitted sometimes may apply course and other credits taken before withdrawal toward the degree. The admitting program will determine at the time of readmission which courses taken by the student may be applied toward the degree and the latest date those courses may be applied. There is no limit, other than that imposed by the program, on how many credits a readmitted student may use from prior admissions to the same degree program. Generally, all courses used toward a degree must be completed within eight years.

With the appropriate background, a student may ask the degree-granting program for permission to waive a required course and substitute a specified, more advanced course in the same discipline. Requests are subject to approval by the student's program, and must be filed with the registrar within one year of the date of matriculation in the program. A program may waive (with specified substitutions) up to three required courses for a single student.

Acceptability of Credit Applicable to an Advanced Degree

Graduate-level credit, obtained from courses, thesis and project work, may be gained for:

- Course work included in the approved Plan of Study completed at the graduate level at WPI.
- Any course work completed at the graduate level and successfully transferred to WPI from other institutions (see Transfers and Waivers). Grades of transferred credits are not added to the WPI transcript.
- Graduate course work completed at the undergraduate level at WPI and not applied toward another degree. Such requests must have the approval of the department.
- With the degree department's approval, up to 9 credit hours applied toward a previous master's degree at WPI or elsewhere may be used in partial fulfillment of the requirements for a second master's degree at WPI.
- Acceptable course work approved for the Combined Bachelor's/Master's Program completed at WPI, provided permission to take courses for graduate credit has been granted.
- All acceptable project work done at the graduate level at WPI. All acceptable thesis work done at the graduate level at WPI. Departments/programs may limit the use of credit depending upon their specific departmental requirements.

Deadlines

Research and teaching assistantships are typically awarded by April 1 for the fall semester. For prospective students requesting such financial assistance, applications must be on file no later than February 1 of the academic year preceding admission. Some programs also offer assistantships beginning in January, with an October 15 application deadline. Applicants who do not seek financial assistance must submit complete applications no later than April 1 to be considered for the fall semester registration, and no later than October 15 for spring semester registration.

Admission to Interdisciplinary Doctoral Programs

WPI encourages interdisciplinary research. Students may apply for admission to interdisciplinary studies directly, but students interested in such options should do so with the assistance of WPI faculty, as these programs require internal sponsorship (see Interdisciplinary Doctoral Programs p.19).

Admission of Students Who Have Not Completed Their Baccalaureate Degrees

In general, students must have earned a bachelor's degree to be admitted, but WPI undergraduate students may apply for the Combined Bachelor's/Master's Program. Interested students should review the requirements listed under Special Programs, and the requirements within the desired graduate department.

Matriculation

Those who wish to pursue the master's or Ph.D. degree should formally apply for admission as early as possible. Non-admitted students may take a maximum of four (4) courses and receive letter grades in most departments; exceptions are 3 course maximum for Biomedical Engineering, Computer Science, and Electrical and Computer Engineering; 2 course maximum for Management. Once these maximums are reached, additional course registrations will be changed to pass/fail and may not be used for degree credit. Therefore, applications should not be delayed beyond the maximum per department.

Each admitted student is assigned an academic advisor. Advisors assist in development of a planned program of study which will meet departmental requirements while at the same time providing the opportunity to explore areas of interest to the individual.

ADMISSION REQUIREMENTS FOR MASTER AND PHD LEVEL DEGREES

Department	GRE	Statement of Purpose	3 Letters of Recommendation	TOEFL
Biology & Biotechnology	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English in not their first language
Biomedical & Clinical Engineering	**Required** for all Applicants/ **Waived** for WPI Alumni & Current Students	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Biomedical Sciences	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Chemical Engineering	**Required** for all Foreign Applicants/ **Recommend** for all Others	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Chemistry & Biochemistry	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Civil & Environmental Engineering	**Recommended** for all Applicants	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Computer Science	**Required** for all Applicants/ **Waived** for WPI Alumni & Current Students	**Required** for all Applicants	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Electrical & Computer Engineering	**Required** for all U.S. Fellowship Applicants/ **Required** for all Foreign Applicants	**Required** for PHD Only	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language Requirement may be waived by the department graduate coordinator after a telephone interview for applicants who have earned their BS or MS degree at a U.S. college
Fire Protection Engineering	**Recommended** for all Applicants	**Required** for Those Without Work Experience	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Management	**GRE** may be substituted for MS and Graduate Certificate Applicants/MBA Applicants must submit **GMAT** scores/Standardized test requirements waived for Applicants with prior graduate degrees	**Required** for all Applicant in the form of a self-evaluation	**Required** for all Applicants	**Required** for all Applicants who's native language is not English and who have not earned a degree from an English-instruction college or university
Manufacturing Engineering	**Required** for all Foreign Applicants/ **Recommended** for all Others	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Materials Science & Engineering	**Required** for all Foreign Applicants/ **Recommended** for all Others	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Mathematical Sciences	**Recommended** for all Applicants	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Mechanical Engineering	**Recommended** for all Applicants	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language
Physics	**Recommended** for all Applicants	**Not Required**	**Required** for all Applicants	**Required** for all Foreign Applicants for whom English is not their first language

* TOEFL waived for Foreign Applicants presently attending a U.S. institution*

FINANCIAL INFORMATION

Financial Aid

Financial assistance to support graduate students is available in the form of teaching assistantships, research assistantships, fellowships, internships and loans. Entering students awarded either teaching or research assistantships will normally receive statements pertaining to the type and level of financial assistance from the Graduate Admissions Office.

The academic standing of students holding awards for teaching and research assistantships is reviewed annually. To remain eligible for a graduate assistantship, a student must demonstrate acceptable progress toward degree requirements, be registered continuously, and maintain a minimum CQPA of 3.0 in courses and research work (A = 4.0).

Teaching Assistantships

Teaching assistantships are awarded to graduate students on a competitive basis. They include tuition support for a maximum of ten credit hours per semester and a stipend. Teaching assistants (TA's) are generally assigned duties that support faculty in their teaching responsibilities. Typical duties of TA's include (but are not limited to) grading of undergraduate and graduate student course paperwork, supervision of undergraduate science and engineering laboratory course sections, as well as individual and small-group conference sections associated with faculty lecture courses. TA's are required to be on campus and available for their assignments 10 days before undergraduate classes begin in the fall, and every day the Institute is open during the academic year, until the spring graduation (see The Academic Calendar). TA's are expected to work 20 hours per week on their assigned duties. Some departments have more stringent requirements. Consult specific departmental descriptions for details.

Research Assistantships

Research Assistants (RA's) are compensated for participating in sponsored research projects in connection with their academic programs. Typical duties of RA's include (but are not limited to) conducting laboratory experiments, assisting in the development of theoretical advances related to faculty research projects, and conducting literature reviews on topics of research interest. Research projects are typically supported by grants and contracts awarded to the Institute by government agencies, industrial firms or other private organizations.

RA's who perform research directly connected to their thesis/dissertation must recognize that research is a full-time professional commitment that must be balanced with the course work required for the desired degree.

The level of support provided to graduate students who have been selected for an assisantship varies depending on the specific nature of the course work, project and student's status. Funds may also be available to support summer research activities for students through Institute or departmental sources, or sponsored research projects. Some provisions exist under which WPI will pay the tuition for a student's graduate program, but provide no support beyond tuition.

GAANN

Graduate Assistants in Areas of National Need or GAANN's are provided through government grants to specific departments and research faculty. WPI has been awarded several of these grants which are available to qualified graduate students.

GEM Fellowships

WPI is proud to be a GEM qualified university. GEM fellowships are awarded to minorities interested in studying science and engineering at the graduate level. For more information, please contact the Graduate Admissions Office at 508-831-5301 or gao@wpi.edu.

Fellowships

Fellowship assistance for graduate students is available in a number of areas. Some departments offer fellowships provided by corporate gifts or philanthropic agencies. The college also directly supports graduate research programs through fellowship awards.

Goddard Fellowships

The Robert H. Goddard Fellowships are awarded to full-time graduate students on a competitive basis. These highly sought awards span the entire research interests of the Institute. The Robert H. Goddard Fellowships are limited to U.S. citizens and provide the recipients with a full 12 month stipend and tuition support. Support required by the student beyond the initial 12 months may be provided by the department in which the student is enrolled, or by a research award from the thesis advisor. Applicants are evaluated on merit by the Faculty Selection Committee, chaired by the Associate Provost for Academic Affairs, from whom application forms and instruction are available. A completed application must be submitted by February 1 to be considered for a fall semester award.

Internships

Graduate internship programs are offered in biomedical engineering, civil and environmental engineering and fire protection engineering. These opportunities are similar to the traditional undergraduate cooperative education concept, except that participating students have already achieved the baccalaureate degree and are working toward a master's degree.

Two options are available for scheduling students' work and study activities: parallel and alternating formats. Under the parallel format, students work part-time and attend classes during the academic year. They may work full-time during the summer. The alternating option permits cycles of full-time work and full-time study. Departments may allow students to take courses during the full-time work cycle. Consult department descriptions for more information.

Student Loans

Financial assistance is also available through the WPI Financial Aid Office in the form of student loans. To qualify, students must be enrolled in a degree-granting program on at least a half-time basis and must be U.S. citizens or permanent residents of the United States. Available loans include the Federal Subsidized Stafford Loan (formerly the Guaranteed Student Loan), the Federal Unsubsidized Stafford Loan and the Professional Education Plan Loan (PEP).

Subsidized Federal Stafford Loan

A low-interest government subsidized loan. Students can borrow up to $8,500 per year with repayment starting six months after graduation. The current interest rate is 8.25%. Eligibility Requirements: Students must qualify for the loan by filing a Free Application for Federal Student Aid (FAFSA) and demonstrating financial need. WPI also requires students to complete an institutional Graduate Personal Data Form and submit financial aid transcripts for all previous schools attended. Students must be enrolled on at least a half-time basis (minimum of 6 credits) and must not be in default on any other educational loans.

Unsubsidized Federal Stafford Loan
A low-interest loan not subsidized by the federal government. Borrowers are responsible for the interest while enrolled. Graduate students can borrow up to $10,000 or Cost, which ever is less. These loans carry the same interest rate as the Subsidized Stafford Loan above. Eligibility Requirements: Students must first apply for the Subsidized Stafford Loan and must not be in default on any other educational loans.

Professional Education Plan Loan
A private, credit-based education loan not subsidized by the federal government. To apply, students only need complete the Graduate Personal Data Form and the application for the loan. Graduate students may apply for up to $7,500 per year under their own names. Principal and interest may be deferred, but interest will accrue while the student is enrolled.

For information on the above loan programs and copies of the forms contact WPI's Financial Aid Office, 508-831-5469.

Withdrawal Policy/Refund

If the student has paid a tuition bill with proceeds from either a Subsidized or an Unsubsidized Federal Stafford Loan and has received a refund for either or both of the loans, the student shall be responsible for any overpayment of funds. It is, therefore, necessary for the student to contact the lender(s) upon withdrawal.

Graduate Student Classifications

- Full-time Degree Seeking:
- Part-time Degree Seeking:
- Non-degree Seeking:
- Graduate Certificate or Advanced Graduate Certificate:
- Student on Graduate Exchange or Internship:

Definition of Full-Time and Part-Time Status:

If a student is registered for 9 or more credits, the student is deemed to be a full-time student for that semester. If a student needs fewer than 9 academic credits to complete degree requirements, registration for the number of credits required for completion of the degree gives the student full-time status. A student pursuing a master's degree, whose Plan of Study shows completion of all degree requirements within a single two-year period, retains full-time status so long as the student complies with that Plan of Study. A student officially enrolled in a graduate internship program has full-time status during the internship period. If a student has completed the minimum number of credits required for a degree, and is certified by the department or program to be working full-time toward the degree, enrollment in one credit of dissertation research (for a student seeking the doctorate), or one credit of thesis research (for a student seeking a master's degree) establishes the student's full-time status. For the purposes of this rule, the semesters are fall (extending from August 15 through December 31), spring (extending from January 1 through May 14), and summer (extending from May 15 through August 14).

Part-time status applies to students who register for 2 to 8 credits per semester.

TUITION AND FEES

Tuition Rate

Tuition for all courses taken by graduate students is based on a $703 fee per semester hour for the 2000-2001 academic year.

Audit Rate

A reduced tuition rate of $351.50 per semester hour for the 2000-2001 academic year is available for those who wish to audit a course. Audit registration cannot be changed to credit once the semester has started.

Tuition Payments

Tuition charges do not include the cost of textbooks. Tuition must be paid-in-full at the time of registration. The following forms of payment will be accepted: Check payable to WPI, American Express, MasterCard, VISA or Discover. (If MasterCard/VISA/Discover accounts are declined, either a penalty fee will be charged or registration will be invalidated. Transcripts may also be held.)

Late Registration

A $25.00 late registration fee will be charged starting September 6, 2000 (fall semester), and January 15, 2001 (spring semester). A $50.00 late registration fee will be charged starting September 12, 2000 (fall semester), and January 22, 2001 (spring semester).

Deferred Payment Plan

A Deferred Payment Plan is available for the fall and spring semesters. By paying a one-time fee per use, students may divide their tuition into three equal monthly payments. For specifics, call the Accounting Office at 508-831-5728.

Deposit

The letter of admission from the Graduate Admissions Office indicates the semester for which approval is granted and requires that the student respond. If accepting an offer for full-time graduate study, the student must submit a $150 nonrefundable deposit. Of this amount, $100 is credited toward tuition, $20 is the Graduate Student Organization Fee and $30 is the Orientation Fee.

Health and Accident Insurance

All graduate students must be covered by health and accident insurance equivalent to that offered under the Student Health and Accident Insurance Plan. Optional coverage for a spouse or dependent may be obtained through a separate policy. Please see the Accounting Office for this coverage. For additional information, please call 508-831-5741.

Orientation

All new full-time graduate students are required to pay a one-time $30 orientation fee. (This is paid by entering students as part of the $150 deposit).

Graduate Student Organization

Each full-time graduate student is charged a fee of $20 per year to support the activities of the Graduate Student Organization. (This fee is paid by entering students as part of the $150 deposit).

GRADUATE FELLOWSHIP OPPORTUNITIES

In addition to the following fellowships, interested students should contact the graduate coordinator in their department for additional sources of funding. Funding includes teaching and research assistantships, corporate and federal sponsored programs and graduate assistantships available to first-year and returning graduate students. Fellowship awards are administered through the Office of the Associate Provost.

Robert H. Goddard Fellowship
Student applications and a details of criteria for eligibility are available in the Graduate Admissions Office and on the web at www.wpi.edu for the Robert H. Goddard Fellowship. Fellowship applications are due in the Graduate Admissions Office no later than February 15 for the class beginning the following fall. Fellowship applications will be considered for students with admission applications on file no later than February 1. This fellowship is reserved for first year graduate students. Recipients receive a monthly stipend and tuition for one year, as a full-time student.

Axel F. Backlin Tuition Scholarship
Department heads may request funding from the Backlin Scholarship on behalf of deserving graduate students by contacting the Associate Provost's Office.

Arvid and Marietta Anderson Fellowship
This fellowship is awarded to an outstanding woman graduate student in her first year of doctoral studies. Preference is given to admission applications completed by February 1.

Fire Protection Engineering Distinguished Scholars Fund
Part of the purpose of this fund is to provide teaching assistantships to students in WPI's graduate fire protection engineering program.

Robert and Esther Goddard Fellowship Fund
This fund is used to underwrite the Robert H. Goddard Fellowship, available to full-time graduate students on a competitive basis.

The Norton Graduate Fellowship
This fellowship is primarily awarded to a first year graduate student in manufacturing engineering.

Robert S. Parks Graduate Fellowship
Established through an endowment, this fellowship shows preference to students in electrical engineering.

Harold Lesher Pierson Memorial Fellowship
This fund is used to support a graduate student whose research is in an area related to medicine that is likely to result in near-term benefits to mankind.

Ralph E. Spaulding Fellowship
Preference in the awarding of this graduate fellowship is given to students in civil engineering.

Helen E. Stoddard Fellowship in Materials Science and Engineering
This fellowship is awarded annually to an outstanding first-year graduate student in the field of materials science and engineering.

Carl and Inez Weidenmiller Fellowship
This fellowship was created from a bequest through the Carl and Inez Weidenmiller Fund.

REGISTRATION INFORMATION & PROCEDURES

The basic requirement for enrollment in a given course is a bachelor's degree from an accredited institution in a relevant field of science or engineering. Although those with management backgrounds may enroll in graduate management courses, no prior management study is required. Persons who have been admitted to graduate study at WPI are given first priority in course registration. Persons not holding a bachelor's degree but who might qualify through training or experience may be allowed to enroll on either a credit or audit basis with permission of the instructor. Registration for graduate courses is on a space-available basis for non-admitted students.

Graduate students are expected to enroll in graduate courses or thesis credit on the registration days designated in the WPI Calendar. Registration on days not designated will obligate additional fees (see Fees). Students should consult with the Registrar's Office for assistance on these matters. Registration is not complete until tuition has been paid. Tuition payment schedules can be arranged with the Business Office.

Degree-Seeking Student Registration

Graduate students must be registered for the semester in which degree requirements are completed. For master of science programs requiring a thesis, the student must register for a minimum of 1 semester credit hour. For a Ph.D. program, the student must register for a minimum of 3 semester credit hours.

Students seeking degrees not requiring a thesis are not required to maintain continuous registration.

Non-Degree Seeking Student Course Registration

Non-degree seeking students are to register for courses in the same manner as all other students. Degree seeking students have preference in registering for courses with limited enrollments. It is important to register as early as possible.

Audit Registration

Students primarily interested in the content of a particular course may register as auditors. Thesis and project work cannot be taken with audit registration. Audit registration receives no credit and receives no grade. Audit registration is controlled in limited enrollment courses. Degree-seeking students receive preferred registration privileges and, as a consequence, audit registration in some courses may be denied. Tuition fees for audit registration are lower than fees for other registrations (see Tuition Payment).

Audit registrants are encouraged to participate in the courses, but typically do not submit written work for evaluation. Often professors will accept written work of audit registrants, but this is left to the discretion of individual instructors.

A student may change from credit to audit registration but may not change from audit to regular credit registration. To change to audit registration for any graduate course, the student must place a petition with the registrar within the first three weeks of class. Forms for change to audit registration are available from the registrar. No fees will be returned to students who change to audit registration.

Admission

Enrollment in a course or courses and satisfactory completion of those courses does not constitute acceptance as a candidate for the master's degree nor admission to graduate study. For students seeking advanced degrees (post-baccalaureate degrees), formal admission to a graduate program is required.

Registration by Mail

Students who have been admitted to degree status will receive registration materials in the mail. These are due prior to the first day of classes.

Walk-In Registration Dates

Fall Semester 2000

Projects and Registrar's Office, Boynton Hall:
- August 28 - September 1 — 8:00 a.m.-4:00 p.m.

Waltham Campus:
- August 28 - August 31 — 8:00 a.m.- 7:00 p.m.
- September 1 — 8:00 a.m.-4:00 p.m.

MetroWest Campus in Southboro:
- August 17 — 5:00 p.m.- 7:30 p.m.

Spring Semester 2001

Projects and Registrar's Office, Boynton Hall:
- January 8 - January 12 — 8:00 a.m.-4:00 p.m.

Waltham Campus
- January 8 - January 11 — 8:00 a.m.-7:00 p.m.
- January 12 — 8:00 a.m.-4:00 p.m.

MetroWest Campus in Southboro:
- January 9 — 5:00 p.m.- 7:30 p.m.

Summer Semester Registration

Graduate students planning to register for project, thesis, independent study or courses during the summer semester should do so through the Projects and Registrar's Office. For information on summer registration, call 508-831-5211.

Transcripts

WPI will issue one transcript of record to a student without charge. Additional transcripts are issued upon receipt of a fee of $4 per copy.

Withdrawal and Incomplete Grades

Because the college makes a financial commitment at the time a course is scheduled for instruction, tuition refunds will be made on the following basis: If notice of withdrawal is received, in writing, in the Projects and Registrar's Office before classes begin, a refund minus $25 will be given; after first class, before second, refund minus $100; after second class, before third, refund minus $200; after third class, before fourth, refund minus $300; after fourth, no refund. A grade of W will be recorded if written notification of withdrawal from the course is received after the third meeting of the class and not later than the following dates:

Fall Semester: November 13, 2000

Spring Semester: March 26, 2001

Withdrawal after these dates is permitted only by petition to the Projects and Registrar's Office. Notice to the instructor or discontinuance of attendance does not constitute withdrawal. Such notice must be submitted in writing to the Projects and Registrar's Office. Incomplete grades are transitional grades and must be changed by the instructor within 12 months. If course work is not made up by this time, the grade automatically becomes an F.

Withdrawal Policy/Refund

If the student has paid a tuition bill with proceeds from either a Subsidized or an Unsubsidized Federal Stafford Loan and has received a refund for either or both of the loans, the student shall be responsible for any overpayment of funds. It is, therefore, necessary for the student to contact the lender(s) upon withdrawal.

Graduate Student Classifications

- Full-time Degree Seeking:
- Part-time Degree Seeking:
- Non-degree Seeking:
- Graduate Certificate or Advanced Graduate Certificate:
- Student on Graduate Exchange or Internship:

Definition of Full-Time and Part-Time Status:

If a student is registered for 9 or more credits, the student is deemed to be a full-time student for that semester. If a student needs fewer than 9 academic credits to complete degree requirements, registration for the number of credits required for completion of the degree gives the student full-time status. A student pursuing a master's degree, whose Plan of Study shows completion of all degree requirements within a single two-year period, retains full-time status so long as the student complies with that Plan of Study. A student officially enrolled in a graduate internship program has full-time status during the internship period. If a student has completed the minimum number of credits required for a degree, and is certified by the department or program to be working full-time toward the degree, enrollment in one credit of dissertation research (for a student seeking the doctorate), or one credit of thesis research (for a student seeking a master's degree) establishes the student's full-time status. For the purposes of this rule, the semesters are fall (extending from August 15 through December 31), spring (extending from January 1 through May 14), and summer (extending from May 15 through August 14).

Part-time status applies to students who register for 2 to 8 credits per semester.

DEGREE REQUIREMENTS

The following are WPI's minimum requirements for advanced degrees. The General Requirements for all advanced degrees must be satisfied to earn any advanced degree. The Additional General Requirements for specific degrees must be satisfied in order to earn the specified degree, regardless of the field in which the degree is earned.

General Requirements for All Advanced Degrees

All degree requirements must be satisfied before the degree is awarded. Exceptions to general and specific degree requirements or to other rules may be made, but only by the Committee on Graduate Studies and Research (CGSR).[1] Requests for exceptions are to be made by written petition to that committee.

At the time the degree is awarded, the student must have been admitted to the graduate program of the degree-granting program. Administratively, a degree-granting program may be a department or a program.

A minimum of two-thirds of the required graduate credit for an advanced degree must have been earned at WPI.

For the master of mathematics, the student must have a program QPA[2] of 2.9 or greater. For all other degrees, the student must have a program QPA of 3.0 or greater.

From time to time, the faculty amends the general and specific degree requirements. To earn a degree, a student must satisfy the graduate rules in effect at a single date. These rules may be those in place on the date of the student's matriculation, those in place on the date of the student's application for graduation, or those in place in a single graduate catalog in effect between the dates of matriculation and graduation. In applying for graduation, the student must specify by year which graduate catalog contains the rules being satisfied.

After the Application for Degree is submitted, all advanced degrees are subject to the final approval of the CGSR, which determines if the student has satisfied the letter and intent of the requirements for advanced degrees.

The CGSR makes its recommendations for the approval of advanced degrees to the faculty of the Institute, which in turn recommends to the president and trustees for their final approval the names of students who should be awarded advanced degrees.

General Requirements for the Master of Science and Master of Engineering

The student must obtain a minimum of 30 credit hours of acceptable course, thesis or project work.

If a thesis is required by the student's program, it must include at least 6 credit hours of research directed toward the thesis, in a project resulting in the completion of an M.S. thesis.

A student completing a master's degree with a thesis option is required to make a public presentation of the thesis. Departments may, at their option, extend the presentation to include a defense of the thesis.

The student must obtain a minimum of 21 credit hours of graduate-level courses or thesis, (18 credit hours for students in the Combined Bachelor's/Master's Program) including at least 15 credit hours of graduate-level courses or thesis in the major field of the student. Other courses (to make up the minimum total of 30 credit hours) may include advanced undergraduate courses approved by the student's program. Such courses are normally considered to be those at the 4000 level. The use of advanced undergraduate courses for satisfaction of graduate degree requirements must be approved by the student's program.
A 1/3 unit WPI undergraduate course taken for graduate credit is assigned 3 credit hours of graduate credit. A graduate student registered for graduate credit in an undergraduate course may be assigned additional work at the discretion of the instructor.

General Requirements for the Doctorate

The student must demonstrate to the faculty high academic attainment and the ability to carry on original independent research.

The student must complete a minimum of 90 credit hours of graduate work beyond the bachelor's degree, or a minimum of 60 credit hours of graduate work beyond the master's degree, including in either case at least 30 credit hours of research.

The student must establish residency by being a full-time graduate student for at least one continuous academic year.

The student must attain status as a doctoral candidate by satisfying specific degree requirements in the student's field.

The student must prepare a doctoral dissertation, and defend it before a Dissertation

Committee, at least two of whose members must be from the student's program, and at least one of whose members must be from outside the student's program. After a successful defense, determined by a majority vote in the affirmative by the Dissertation Committe, the dissertation must be endorsed by those members of the Dissertation Committee who voted to approve it. The completed dissertation must follow in format the instructions published by the library. After final approval for format of the dissertation, the Associate Provost for Academic Affairs will notify the registrar that the dissertation has been approved.

Once a student has satisfied the departmental candidacy requirements, the student will be permitted to enroll for dissertation credits. Prior to completion of candidacy requirements, a student may enroll for no more than 18 credits of directed research.

Minimum Requirements for a Social Science Interdisciplinary PhD

In addition to the general requirements established by WPI for an interdisciplinary doctoral degree, applicants must pass a qualifying examination. This examination will test the basic knowledge and understanding of the student in the disciplines covered by the research as is normally expected of degree holders in the disciplines. It must be administered within the first eighteen credits of registration in the interdisciplinary Ph.D. program. The examination will be administered by a committee of no less than three members, approved by CGSR, respresenting the disciplines covered by the research. Students are allowed at most two attempts at passing the examination, and may take a maximum of 18 credits prior to passage.

Other Degrees

Requirements for the master of business administration, and master of mathematics for educators appear under the descriptions of the awarding programs. Students in the Combined Bachelor's/Master's Program are subject to additional rules described in the next section.

General Requirements for the Combined Bachelor's/Master's Degree Program

Only registered WPI undergraduates may enter the Combined Program. To enter, a student must apply to the WPI Graduate Program. Admission to the Combined Program is made by the faculty of the program that awards the graduate degree. A student in the Combined Program continues to be registered as an undergraduate until the bachelor's degree is awarded.

While in the Combined Program, a student may continue to take courses or projects toward the undergraduate degree; the student may also register for graduate courses, projects, directed research or thesis credits toward the master's degree.

To obtain a master's degree via the Combined Program, the student must satisfy all requirements for that master's degree, including any requirements of the graduate degree-awarding program for satisfactory completion of specified courses or a master's thesis. To obtain a bachelor's degree via the Combined Program, the student must satisfy all requirements for that bachelor's degree, including distribution and project requirements.

A student in the Combined Program, may, within the program limit and with prior approval, use the same courses toward the bachelor's and master's degrees. The limitation is computed from the graduate credit hours for each course. Courses, whose credit hours total no more than 40% of the credit hours required for the master's degree, and which meet all other requirements for each degree, may be used to satisfy requirements for both degrees. Such courses are recorded on the transcript using the credit hours/units and grades appropriate at the graduate or undergraduate levels. For students in the Combined Program, approved undergraduate courses are assigned graduate credit with a conversion rate of 1/3 WPI undergraduate unit = 3 credit hours, while graduate courses applied toward the undergraduate degree are awarded undergraduate credit with a conversion rate of 1 credit hour = 1/9 undergraduate unit.

Students in the Combined Program may use advanced undergraduate courses to satisfy graduate degree requirements. The department 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.

If the programs awarding the bachelor's and master's degrees are not the same, the program awarding the graduate degree may require that the student's Major Qualifying Project relate in some way to the graduate program's discipline. The graduate program may also make other requirements as it deems appropriate in any individual case. These requirements take the form of a written agreement (obtain form from the Graduate Admissions Office) between the student and the graduate program, which must be completed and filed with the registrar before the student may be matriculated in the Combined Program.

Additional requirements appear within each department's section in this catalog.

The Combined Program is a full-time* program of study on both the bachelor and master's level. Once admitted to the Combined Program, a student must register every fall and spring semester until the graduate degree is completed. A student in the Combined Program who, during the fall or spring semester, has no registered activities is automatically terminated from the Combined Program, and may only be readmitted to the Combined Program by 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.

Students usually apply for admission to combined degree status in their sophomore or junior year of WPI undergraduate study.

Some graduate-degree-awarding programs impose additional restrictions on students in the Combined Program. Consult the degree requirements of individual programs for details.

[1] CGSR - The Committee on Graduate Studies and Research (CGSR) is concerned with all post-baccaluaureate programs of the university, and reviews and recommends changes in WPI policies on goals, student recruitment, admissions, academic standards, teaching and research assistantships, scholarships and fellowships. It also makes recommendations to the Faculty and Administration on new graduate programs and courses and changes in programs and courses. The Committee acts on admission of graduate students to degree candidacy, dismissal for failure to meet academic standards, and student petitions on academic matters. It brings to the Faculty for action the names of students who it has determined are eligible for post-baccalaureate degrees. The Committee reviews and recommends changes in policy on the funding, promotion, and conduct of research at WPI.

[2] QPA - The Quality Point Average (QPA) is calculated as the sum of the products of the quality points and credit hours for each registered activity, in the average, divided by the total number of credit hours for all registered activities in the average. Quality points are as follows: A = 4.0; B = 3.0; C = 2.0; D = 1.0; and F = 0.0.

* Full time study means a minimum registration of at least 9 credit hours.

THESIS AND DISSERTATION

The Gordon Library publishes the Regulations for Preparation of Thesis and Dissertation on its website at http://www.wpi.edu/+library/pubs/thesis/. Students preparing a thesis or dissertation should read these regulations carefully before, during, and following the actual writing process.

In the spring of 1999, WPI became a member of the Networked Digital Library of Theses & Dissertations. This organization is dedicated to "unlocking access to graduate education" by making the full text of theses and dissertations available online. The 2000-2001 academic year will be a period of transition as WPI moves from paper to electronic archiving.

Most documents will be made available to the general public, but individual authors may choose to restrict their work to be accessible only by members of the WPI Community or to be completely unavailable for a period of up to five years. Factors in this decision should include copyright, intellectual property, and patenting concerns. Students should discuss these issues thoroughly with their advisors and committee members, as their signatures are required on the approval form.

Beginning in the 1999-2000 academic year, students have the following options for submitting theses and dissertations to fulfill the University requirements:

- Submit only an electronic version, following the guidelines on the ETD website (http://www.wpi.edu/Pubs/ETD/). Early approval of students' advisors is crucial to success - interested students should discuss this option thoroughly with their advisors.
- Submit a paper copy, following the Regulations for Preparation of (Paper) Theses and Dissertations (http://www.wpi.edu/+library/Pubs/Thesis/).
- Submit both paper and electronic, with the paper copy fulfilling the University regulations.

In order to submit theses and dissertations electronically, students must have a WPI account, obtainable online using a PIN provided by the Projects & Registrar's Office. An approval form, available for download from the website, is required by the Gordon Library for electronic submission, including a copy of the signed title page. Students interested in submitting electronically should print a copy of this form and of their title page and obtain the necessary signatures of advisors and committee members following the presentation or defense.

Theses and dissertations submitted electronically are archived in Portable Document Format (PDF). PDF conversion software is available on the WPI Novell Network, and PostScript, DVI, and Word Documents will also be accepted and converted to PDF as necessary. Training sessions will be held throughout the year, and information about creating and submitting ETD's is available online at http://www.wpi.edu/Pubs/ETD/. Interested students should visit the website first, and then e-mail etd-questions@wpi.edu or call 508 831-5963.

Application for Graduation/Application for Advanced Degree

One of the final stages of an advanced degree program is the presentation of the student's complete (or nearly complete) program for final departmental and collegiate review. This process constitutes the Application for Degree. In the final semester (and prior to February 12 for May, June 4 for October and November 1 for February degree granting) each student must complete and submit an Application for Graduation to the Projects and Registrar's Office. The application is then sent to the Committee on Graduate Studies and Research.

The Application for Degree form lists all the advanced degree credit (and other activities) relevant to obtaining an advanced degree. The student presents a list of courses (completed or currently enrolled in), project activities and research activities that meet the degree requirements of the program. This is the student's completed Plan of Study. Application forms may be obtained from the Projects and Registrar's Office and must be prepared in consultation with the academic advisor. In order to have the application acted upon, the student submitting the application must be registered for at least one credit during the semester in which the application is submitted.

The student, registrar and department will be notified if the Application has been approved by WPI's Committee on Graduate Studies and Research. It is the individual student's responsibility to initiate action on the Application for Graduation. The student should inquire at the Projects and Registrar's Office about the application no later than the beginning of the final semester of work toward the degree.

Thesis Binding

A thesis/dissertation binding fee must be paid at the Accounting Office. The fee is $10 per copy. A minimum of four bound copies is required: two for the library, one for the thesis advisor, and one for the department.

ADVANCED DISTANCE LEARNING NETWORK

Distance Learning Program

In 1979, WPI's commitment to active, lifelong learning prompted the creation of the Advanced Distance Learning Network (ADLN), a partnership between several academic departments and WPI's Instructional Media Center. ADLN programs enable working professionals to continue to grow within their chosen field without having to make repeated trips to the WPI campus.

Delivery Media

ADLN courses consist of the same content and materials as on-campus class meetings. Courses originate in one of WPI's studio classrooms and are delivered to ADLN students via interactive compressed video, expressed-mail videotapes, or the World Wide Web, depending on the facilities available to the student. Materials such as books, handouts, and supplemental readings are sent by express mail, fax, e-mail or are posted on the World Wide Web. An e-mail account and access to the World Wide Web are required for participation in an ADLN course.

Programs of Study

ADLN offers a Master of Business Administration (M.B.A.), a Master of Science (M.S.) in fire protection engineering, and a Master of Science (M.S.) in civil and environmental engineering. In addition to these degree options, WPI's ADLN also offers numerous graduate certificate programs in these areas.

The M.B.A. program focuses on the management of technology and features a highly integrative curriculum that emphasizes leadership, ethics, communication, and a global perspective. Concentration areas include MIS, technology marketing, technological innovation, operations management entrepreneurship, and management of technology. This 49-credit M.B.A. program may be reduced to as few as 31 credits with an appropriate academic background. A customized 15-credit graduate certificate program in management is also available.

The Fire Protection Engineering (FPE) program is oriented toward developing a well-rounded professional who can be successful in a competitive career environment. The curriculum is designed to teach students current standards of practice and expose them to state-of-the-art research literature that will support future practices. In addition to the 10 course (30-credit) M.S. option, professionals with a B.S. degree in an engineering technology or science field who complete four thematically-related FPE courses can receive a Graduate Certificate in FPE. Master's degree holders may instead opt to complete five thematically-related courses for an Advanced Certificate in FPE.

The Civil and Environmental Engineering programs are arranged to meet the interests and objectives of individual students and their corporations. The curriculum focuses on today's environmental issues and their relationship to engineering, business, and law. The 33-credit Master of Science degree is a professional practice-oriented degree designed to meet the continuing challenges faced by practicing environmental engineers. A four-course Graduate Certificate is also available through ADLN.

Credits earned in any WPI certificate program can later be applied toward an advanced degree, contingent upon formal admission to graduate study. A maximum of two courses taken at WPI as a nondegree-seeking student may be applied for credit to the M.B.A. program; a maximum of four courses taken at WPI as a nondegree-seeking student may be applied for credit to an M.S. in fire protection engineering or an M.S. in civil and environmental engineering.

Special Programs

ADLN and appropriate academic personnel are always willing to consider the addition of new programs when there is sufficient interest.

Student Services

Academic advisers are assigned upon admission. Online library services are free and reference services are available by telephone and e-mail. Dial-up UNIX accounts (for e-mail, etc.) and career placement and counseling are available for matriculated students. Books may be ordered toll-free from the WPI bookstore (888-WPI-BOOKS) and are typically delivered one to three days after ordering.

Credit Options

The M.B.A. program allows 18 foundation-level credits to be waived for those with appropriate academic backgounds, either via straight waivers for those with appropriate course work completed within the past six years with a grade of B or better or via waiver exams. The M.B.A. program, the M.S. in fire protection engineering, and the M.S. in civil and environmental engineering allow students to transfer up to 9 credits from graduate-level course work at other schools. Graduate and advanced certificate programs require all credits to come from WPI.

Faculty

Management has 26 full-time members and 10 part-time members, 24 of whom have Ph.D. degrees. Fire Protection Engineering has 5 full-time faculty members, all with Ph.D. degrees, and 2 part-time professors. Civil and Environmental Engineering has 13 full-time faculty, all with Ph.D. degrees, and 8 part-time professors.

Tuition and Fees

Tuition is $703 per credit ($2,109 per 3-credit course) for all programs in the 2000 - 2001 academic year. Students wishing to earn Continuing Education Units (C.E.U.'s) instead of graduate credit may opt to audit courses at half tuition.

Financial Aid

Loan-based aid is available only through special arrangements. Students must be registered on a half-time basis (two courses per semester) or greater.

Contact

Pennie S. Turgeon, Director,

Advanced Distance Learning Network

Worcester Polytechnic Institute

100 Institute Road

Worcester, Massachusetts 01609-2280 U.S.A.

(508) 831-5810 (V)

(508) 831-5881 (F)

adln@wpi.edu

http://www.wpi.edu/Academics/ADLN

FACILITIES & SERVICES

Books for Off-Campus Courses

Textbooks for off-campus courses are brought to the first meeting of the course, for sale at that time. Students who have not previously purchased their books should be prepared to pay by cash, check or credit card. Checks should be made payable to "Tatnuck Bookseller @ WPI." Textbooks for remote ADLN registrants will be sent via UPS to the participant, pending advanced payment. The textbooks may be ordered through the Bookstore by calling toll free 888-WPI-BOOKS. Individuals taking Advanced Distance Learning Network courses at remote locations should call 888-WPI-BOOKS to arrange for textbook shipment.

Bookstore

The Bookstore, located on the first floor of Daniels Hall, will be open during the first days of classes from 8:30 a.m. to 7 p.m. During the rest of the school year, hours of operation are 8:30 a.m. to 7 p.m. Monday through Thursday, 8:30 a.m. to 5 p.m. Friday, and 11 a.m. to 4 p.m. on Saturday. For more information please call toll free **888-WPI-Books or e-mail wpi@tbsol.tatnuck.com.**

Campus Police

The WPI main campus is protected by a police force on-duty 24 hours a day. The Campus Police Office is located at 35 Dean Street. An escort service is available after dark for students who live near campus and to escort students to parking lots and other on-campus locations. The Campus Police phone number is **508-831-5433**. Southborough police can be reached at **508-366-3060**; Waltham police at **781-893-1212**.

Career Development Center

The Career Development Center (CDC) at WPI assists students in the development of life-long skills related to careers and the job search process. CDC serves not only to undergraduate students but graduate students and alumni as well. Information and guidance is provided in the areas of full-time employment, graduate school, part-time employment, Cooperative Education and summer positions. Call **508 831-5260**.

Class Cancellation

Classes are rarely canceled because of inclement weather. However, if in doubt you may call the WPI switchboard, the Graduate Admissions Office, or **508-831-5744** to find out if a particular class has been canceled. When all classes are canceled (severe weather during the mid-day period, forecast to last through evening) cancellation will be broadcast on radio stations WTAG, WSRS, WAAF, WFTQ, WKOX and WBZ.

Computer Resources

WPI's Fuller Laboratories provide dedicated space for faculty, staff and students working in the information sciences. The WPI College Computer Center (CCC) is located in this building, along with the Computer Science Department and the Instructional Media Center.

CCC provides a wide range of services and access to computer resources for the WPI community and manages an array of powerful UNIX workstations. All WPI students, faculty, and staff can obtain a login ID at CCC for academic course work, research, and self-education. The ID will remain in force as long as the person continues to be registered as a student or to be employed by WPI. The systems have been configured so that the user will see the same familiar environment no matter which CCC workstation is used.

CCC facilities are accessible from a wide variety of locations on campus, or via modem, or from around the world via the Internet. CCC operates the campus data network, the modem bank, and the Internet connectivity. Computer systems operated by academic departments are also on the same CCC communications infrastructure, so they are accessible just as easily.

CCC manages a computer help desk to answer users' questions on any of the computer platforms and provide short instruction sessions on supported software. CCC also provides technical support for endorsed packages. Several special computer environments are maintained, including several PC classrooms and open-access PC laboratories.

CCC is generally open from 1 p.m. Sunday until 11 p.m. Friday (24 hours a day) and Saturday 10 a.m. to 5 p.m. during the academic year. When WPI is not in session and during undergraduate "term breaks," as well as summer session, hours will be posted at CCC. Assistants are available at both CCC and the PC Lab to help students with special requests.

To reach the CCC help desk call **508-831-5888** or e-mail: helpdesk@wpi.edu.

Extracurricular Activities

The Institute provides a varied program of sports and recreation. Graduate students usually enter teams in several intramural sports, and may participate in certain intercollegiate club sports as well as on-campus musical or theater groups.

There are outstanding athletic facilities for tennis, swimming, squash, basketball, racquetball and volleyball, as well as a weight-lifting room, a fitness center, a sauna and several outdoor playing fields. Graduate students frequently join faculty groups for noontime jogging, aerobics and basketball.

A wide variety of entertainment is brought to the campus, ranging from small informal groups to popular entertainers in the 3,500-seat Harrington Auditorium. A series of films is shown in Perreault Hall, and chamber concerts are presented in the Baronial Hall of Higgins House.

The normal social activities of a medium-sized city are readily accessible, many within easy walking distance. Other activities of interest to students are offered by the many colleges in the Worcester Consortium (see Intercollege Studies and the Consortium).

Gordon Library

The George C. Gordon Library supports the informational and research needs of the WPI graduate community. The library staff works closely with each department to augment library resources pertinent to graduate and other research interests. The collection currently numbers over 345,000 volumes and includes subscriptions to over 1,200 current periodicals. The collection also includes undergraduate project reports; graduate theses and dissertations; and the WPI Archives and Special Collections. Library resources come in many formats: print, audio, video, and digital.

Gordon Library is open over 100 hours each week during the academic year. Many services and resources are also available to graduate students twenty-four hours a day via the library's World Wide Web based system. Here students can access the Gordon Library catalog; local and remote library catalogs; bibliographic databases; full-text articles in electronic periodicals; and other reference tools and resources located anywhere in the world.

In addition to the Gordon Library's resources, WPI students may utilize the collections of other Worcester area libraries. Students with a WPI identification card can borrow books directly from the libraries at Anna Maria College, Assumption College, Becker College, Clark University, College of the Holy Cross, University of Massachusetts Medical Center, and Worcester State College. Students also can request materials not owned by Gordon Library through the interlibrary loan and document delivery services. Before classes begin each semester, library staff offer orientation sessions to graduate students. Throughout the year, members of the Reference Department conduct both library and Internet orientation and instruction sessions. Gordon Library staff will consult with students in the preparation of theses and dissertations. Standard reference guides are also available. A pamphlet, Regulations for Preparation of Theses and Dissertations, prepared by the library staff and sponsored by the Office of Academic Affairs, is available to all graduate students.

Open Monday-Thursday 8 a.m.-midnight, Friday 8 a.m.-11 p.m., Saturday 9 a.m.-9 p.m., and Sunday noon-midnight. During the weeks when there are no undergraduate classes and during the summer, hours are posted at the library. For more information, call **508-831-5410**.

Housing

A limited amount of on-campus housing is available for single graduate students. There is no on-campus housing available for married students. Most graduate students live in rooms or apartments in residential areas near the campus.

For information regarding on-campus housing, as well as listings of off-campus accommodations, contact the Residential Services Office, **508 831-5645**.

International Graduate Student Services

The Office of International Students and Scholars is located in WPI's International House at 28 Trowbridge Road. The office provides information and assistance on immigration and other regulatory matters, information on cultural and social programs and services as well as general counseling.

The International House also serves as a meeting place for international students with its lounge area, meeting room and resource room. WPI's English as a second Language Program is located in the house. The house also offers limited temporary housing for international graduate students.

Office of International Students and Scholars: **508-831-6030**. ESL Director: **508-831-6033**.

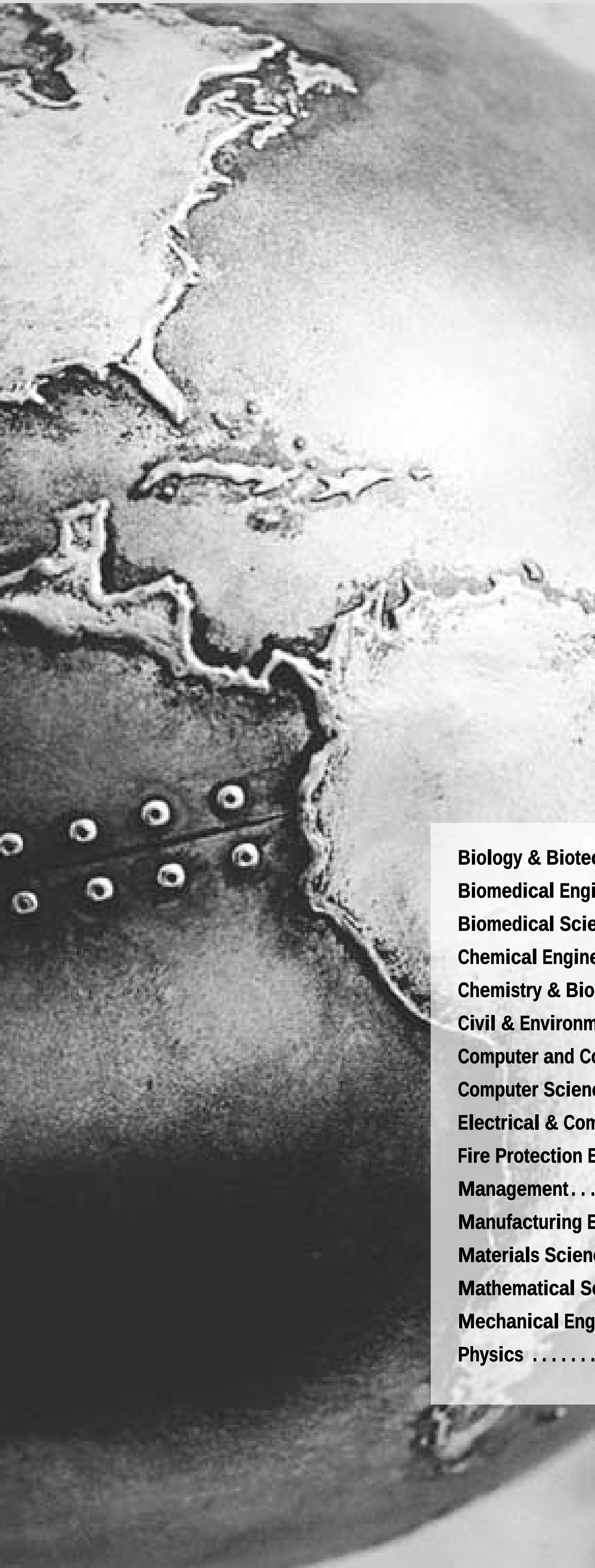
Student ID Cards

The Student ID Card serves as a library charge card. Anyone without an ID must pay a fee of $8.00 to obtain one. Arrangements will be made at the beginning of each semester to provide ID cards for those registered in the Evening Program (usually the day of the first class meeting between 5 and 6:30 p.m. in the lower level of Boynton Hall). You may obtain a current validation sticker at the time of registration, or with a completed registration form when obtaining a new ID. Additional opportunities are available throughout the school year to obtain an ID. For details, call **508-831-5150**.

Student Life

The Student Life Office staff is available to students enrolled in the Evening Program to assist with any out-of-the-classroom concerns that may arise. Staff members are available between 8:30 a.m. and 5 p.m. Appointments outside of these hours can be arranged by calling **508-831-5201**.

DEPARTMENTS • PROGRAMS • SPECIALIZATION



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Biology & Biotechnology

Programs of Study

Students in the biology master's program learn to apply basic principles of the discipline to solving research problems, and broaden their knowledge of the subject through formal course offerings. Graduates with this degree may pursue further graduate education or choose to work in a research, clinical or industrial setting, applying their expertise to practical problems. The structure of this program is unique in that several graduate courses include one component derived from our higher-level undergraduate offerings and a second component involving conferences, seminars and the study of current articles from the literature.

Faculty

R. D. Cheetham, Professor and Head; Ph.D., Purdue University

J. C. Bagshaw, Professor; Ph.D., University of Tennessee

J. E. Miller, Professor; Ph.D., Case Western Reserve University

P. J. Weathers, Professor; Ph.D., Michigan State University

D. S. Adams, Associate Professor; Ph.D., University of Texas at Austin

T. C. Crusberg, Associate Professor; Ph.D., Clark University

S. M. Politz, Associate Professor; Ph.D., University of California at Los Angeles

J. Rulfs, Associate Professor; Ph.D., Tufts University

A. DiIorio, Affiliate-Assistant Professor; Ph.D., WPI

D. G. Gibson III, Assistant Professor; Ph.D., Boston University

S. S. Kohles, Collaborative Assistant Professor; Ph.D., University of Wisconsin

P. Robakiewicz, Assistant Professor; Ph.D., University of Connecticut, Storrs

E. Ryder, Assistant Professor; Ph.D., Harvard Medical School

J. Whitefleet-Smith, Senior Lab Instructor; Ph.D., University of Wisconsin

J. Tyler, Assistant Professor; Ph.D., SUNY, Albany

J. Krushkal, Assistant Professor; Ph.D., University of Texas, Houston

Biotechnology is a rapidly developing field with many subdisciplines (e.g., the utilization of biological systems for industrial secondary product synthesis and bioconversion processes). The speed at which such areas of technology have grown has been boosted by the recent developments in microbial genetics, immunology, microorganism selection and DNA technology. Our program is aimed at satisfying the requirements of a sound background in both biology and a supporting field of technology.

Experts in biotechnology will be required to lead the biotechnology industry into the next century to compete in a global economy. Furthermore, many of these students will be actively involved in teaching activities if not at the academic level, then within their corporations. Good educational skills are paramount to successful presentations and communication on a global level. The program is interdisciplinary, with two special features in addition to the expected technical training: improvement in communication skills through teaching and delivery of seminars; and better preparation of our students for multinational careers.

Graduates develop a rigorous understanding of biology, particularly in the areas of microbiology, fermentation genetics, DNA technology and genetic engineering, in addition to a background in the technological aspects of biology. Such training allows the meaningful interaction of engineers with biologists who are fully capable of appreciating engineering concepts and methods, with a view to choosing, selecting or constructing organisms or other biological systems for the solution of practical problems. This is a broad and challenging program allowing specialization in topics as diverse as pharmaceutical production, hazardous wastes, animal and plant tissue culture, microbial fermentation, computer applications, and aspects of the chemical industry.

Biology and Biotechnology Laboratories

Bioprocess Laboratory

The Biology and Biotechnology Department has a state-of-the-art 1600-square-foot laboratory to be used for courses and projects in bioprocess engineering (the application of biotechnology and engineering principles to produce products). This lab houses the latest equipment for fermentation, centrifugation, tangential flow filtration, spectrophotometry, and high-performance liquid chromatography. The lab is used for courses in recombinant DNA, fermentation, downstreams processing, and a course in scale-up that gives students experience in bioprocessing at the 50-liter scale. This combination of facilities and courses gives WPI students experience unmatched by any other university in the country.

Degree Requirements

For the M.S. in Biology

In addition to the WPI requirements, a thesis project (minimum of 6 credit hours) is required for the degree. An advisory committee of three faculty members reviews and approves each student's program of study and thesis research.

For the M.S. in Biotechnology

In addition to the WPI requirements, a thesis project (minimum of 6 credit hours) is required for the degree. A minimum of 9 credit hours is required in graduate course work outside the Biology and Biotechnology Department and within a single discipline. Course selections must be approved by an advisory committee of three faculty members.

For the Ph.D. in Biotechnology

In addition to the WPI requirements, a thesis project (minimum of 30 credit hours) is required. It is the intention of the faculty that the student develop for this degree a thematic focus for a minor, interdisciplinary area of study outside of the Biology and Biotechnology Department, such that the following credit distribution be required for course work:

15 cr. minimum BB courses at the 4000 or 500 level (an M.S. in a biological field may be considered acceptable)

15 cr. minimum within the minor area of study and taken at the 4000 or 500 level (M.S. in an appropriate minor field of study may be considered acceptable)

15 cr. maximum at the 4000 level or below for all requirements

2 cr. minimum to meet the cultural studies requirement

2 cr. minimum to meet the teaching skills requirement

Teaching Requirement
(2 cr. minimum) The objective of this requirement is formal training in pedagogy. It can be fulfilled by enrolling in: (a) an advanced undergraduate or graduate course in education; or (b) a mentored teaching experience (IS/P) arranged with an individual faculty member, within the major discipline of the student and the professor. This mentored teaching experience is distinguished from a teaching assistantship in that it requires significant mentored student involvement in course development, delivery, and evaluation.

Cultural Studies Requirement
(2 cr. minimum) Graduates of the biotechnology program will need more than technical skills to make their way in the global market. Such skills might include bioethics and linguistic and interpretive skills that encourage a reasoned awareness and acceptance of human differences. Students may choose from offerings in bioethics, history and language to develop a focused strength in one area. Graduate work in Cultural Studies is a minimum of 2 credit hours done through a humanities #4 type IS/P under the guidance of a humanities advisor. For example, a student could register for ISP4 Bioethics for 2 credits.

Publications
In order to graduate, at least one manuscript should be submitted for publication in a refereed journal and at least one paper must have been presented at a national or international conference.

Exams and Reports
A Ph.D. qualifying exam is required and normally taken following the first year of study. Candidates for the Ph.D. must give a public seminar on their dissertation research, to be followed immediately by a defense of the dissertation before an examining committee. The dissertation examining committee should include the student's Advisory Committee. In all cases, the committee must include at least two members of the WPI faculty. All members of the examining committee must be present for the public presentation and subsequent defense. In the absense of unanimous approval, the dissertation examining committee may vote to pass the student with no more than one dissenting vote. The dissertation will be signed by those members voting for approval. If the student fails the dissertation defense, he/she may repeat the defense within no more than six months from the date of the failed defense. A second failure will result in dismissal from the program. The following reports are also required: Dissertation research proposal required and accepted by committee; Progress reports: Annual to committee; Seminars: 1 per year on research or a technical topic as advised by committee. May be given as part of a seminar course.

Course Selection
Course selections must be approved by an advisory committee composed of two faculty members from BB and at least one faculty member or equivalent from another appropriate discipline. These can be either from other departments at WPI or from off-campus groups (e.g., Worcester Foundation, University of Massachusetts Medical School, a biotechnology company, etc.).

Dissertation Defense
Candidates for the Ph.D. must give a public seminar on their dissertation research, to be followed immediately by a defense of the dissertation before an examining committee. The dissertation examining committee should include the student's Advisory Committee. In all cases, the committee must include at least two members of the WPI faculty. For students in the Consortium Ph.D. in Biomedical Sciences, the dissertation examining committee must include at least one member of the Steering Committee of the Consortium. All members of the examining committee must be present for the public presentation and subsequent defense.

The dissertation examining committee will pass the student unanimously or with no more than one dissenting vote. The dissertation will be signed by those members voting for approval. If the student fails the dissertation defense, he/she may repeat the defense within no more than six months from the date of the failed defense. A second failure will result in dismissal from the program.

Admission Requirements

Applicants should possess a sound undergraduate background in the sciences and mathematics. A B.S. or equivalent in biology or chemistry is required for the biology master's program. A biology, chemistry or chemical engineering B.S. or equivalent for the biotechnology master's program. For the Ph.D., a B.S., B.A. or M.S. is required; a QPA of 3.2 is recommended, with a 3.0 minimum acceptable for provisional admission.

Applicants will be interviewed by the department's Graduate Admissions Committee whenever possible. Degree candidacy for all participants must be confirmed within the first academic year. Students lacking some of the requirements for admission may still apply to the program provided they realize that deficiencies identified by the committee must be rectified before confirmation of their candidacy for the degree.

For the Ph.D. in Biomedical Science
The Department of Biology and Biotechnology administers the Worcester Consortium Ph.D. Program in Biomedical Science. This innovative program is designed for students who already have substantial post-baccalaureate research experience, such as an M.S. degree and/or several years of laboratory research employment. The Consortium includes WPI, Clark University, the University of Massachusetts Medical School, and the Worcester Foundation for Biomedical Research. Students who enter the program through WPI are considered WPI graduate students in the Department of Biology and Biotechnology and will receive their degree from WPI, but may conduct dissertation research at any of the Consortium institutions. Students who enter the program through WPI must satisfy the general degree requirements of WPI as well as requirements specified by the Department of Biology and Biotechnology. A complete description of procedures and degree requirements is available in the Department Office. A more extensive description of the program is found on page 30.

Biomedical Engineering

Programs of Study

The goal of the biomedical engineering graduate program is to apply engineering principles and technology as solutions to significant biomedical problems. Students trained in these programs have found rewarding careers in major medical and biomedical research centers, academia, the medical care industry, and entrepreneurial enterprises.

There are three master's options in biomedical engineering: the Master of Science in Biomedical Engineering, the Master of Engineering in Clinical Engineering and the Master of Engineering in Biomedical Engineering. While the expected levels of student academic performance are the same for all options, they are oriented toward different career goals. The Master of Science option in Biomedical Engineering is oriented toward the student who wants to focus on a particular facet of biomedical engineering practice or research. The Master of Science can serve as a terminal degree for students interested in an in-depth specialization.

The clinical engineering Master of Engineering program is for those individuals interested in employment in hospitals or other clinical environments. This subspecialty involves a close interaction with patients and the health care delivery system. An internship experience is required of all students in the clinical engineering program.

The Master of Engineering program is considered to be a terminal professional degree.

There are two Ph.D. options in biomedical engineering: The Ph.D. in Biomedical Engineering at WPI and the Ph.D. in Biomedical Engineering and Medical Physics offered jointly by WPI and the University of Massachusetts, Worcester (UMW). In both programs, the degree of doctor of philosophy is conferred on candidates in recognition of high attainments and the ability to carry on original independent research. Graduates of the program will be prepared to affiliate with academic institutions and the growing medical device and biotechnology industry, which have become major economic factors in the Commonwealth of Massachusetts.

The Joint WPI/UMW Ph.D. Program employs the advanced technical knowledge and expertise of engineering and medical faculty to provide students with the knowledge and skills necessary to apply engineering and scientific principles to medically related problems. A unique aspect of this program is that it utilizes the expertise and resources available from a public university and a private institution of higher education in a synergistic manner to train students in the application of engineering to medical research. The Ph.D. degree in this program is awarded jointly by WPI and UMW, with the appropriate designation on the diploma.

Faculty

C. H. Sotak, Professor and Head; Ph.D., Syracuse University

K. G. Helmer, Research Assistant Professor; Ph.D., University of Rochester

S. S. Kohles, Assistant Professor; Ph.D., University of Wisconsin-Madison

S. Kun, Research Assistant Professor; Ph.D., WPI

Y. Mendelson, Associate Professor; Ph.D., Case Western Reserve University

R. A. Peura, Professor; Ph.D., Iowa State University

R. D. Shonat, Assistant Professor; Ph.D., University of Pennsylvania

Research Interests

Biomedical Sensors

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. (Mendelson, Peura, Kun)

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 (UMMS). Collaborative orthopedic research on large and small animals is being conducted at Tufts University School of Veterinary Medicine (TUSVA). Current on-campus studies include the measurement and analysis of kinetics and kinematics of human and animal motion and improving the mechanical design of minimally invasive medical instruments. Also, flow-patterns at arterial stenosis 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 interactions. (Kohles, Hoffman, Savilonis)

Cardiac Electrophysiology

Development of automated systems for data acquisition, analysis and display of endocardial ECG signals. Development of detection systems for heart wall motion and catheter ablation instrumentation. Analysis of parameters for optimization of biological tissue impedance contrast. (Peura, Kun)

WPI Faculty Associated With the Program

D. Cyganski, Professor of Electrical and Computer Engineering; Ph.D.,WPI

W. W. Durgin, The K. G. Merriam Professor of Mechanical Engineering and Associate Provost for Academic Affairs; Ph.D., Brown University

A. H. Hoffman, Professor of Mechanical Engineering; Ph.D., University of Colorado

F. J. Looft, Professor of Electrical and Computer Engineering; Ph.D., University Michigan

P. C. Pedersen, Professor of Electrical and Computer Engineering; Ph.D., University of Utah

B. J. Savilonis, Professor of Mechanical Engineering; Ph.D., State University of New York, Buffalo

H. K. Ault, Associate Professor of Mechanical Engineering; Ph.D., WPI

D. DiBiasio, Associate Professor of Chemical Engineering; Ph.D., Purdue University

M. A. Gennert, Associate Professor of Computer Science; Sc.D., Massachusetts Institute of Technology

R. S. Quimby, Associate Professor of Physics; Ph.D., University of Wisconsin, Madison

S. Shivkumar, Associate Professor of Mechanical Engineering; PhD., Stevens Institute of Technology

J. Sullivan, Professor of Mechanical Engineering; Ph.D., Dartmouth College

M. O. Ward, Professor of Computer Science; Ph.D., University of Connecticut

D. G. Gibson III, Assistant Professor of Biology and Biotechnology; Ph.D., Boston University

Instrumentation
Development and comparison of various tissue pH monitors. Development and evaluation of an oxygen flow meter for use during open-heart surgery. WPI, in cooperation with University of Massachusetts Medical School, has demonstrated the ability of impedance, ultrasound, bruit sounds and photoelectric plethysmography to detect vascular flow obstructions. Current work attempts to improve the sensitivity and quantitative accuracy of these techniques and to extend them to other cardiovascular measurements. (Mendelson, Peura, Kun)

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) studies of metabolic function and oxygenation in the brain, 2) studies investigating the role of oxygen in diabetic retinopathy, 3) development of instrumentation and techniques for detailed physiologic studies in inbred, transgenic, and knockout mouse models, 4) development of instrumentation and imaging techniques for 3-dimensional in vivo imaging in neural tissues, and 5) development of instrumentation for spectral imaging of neural tissues during functional activation. (Shonat)

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. (King, Karellas, Glick, Gennert, Cyganski, Davis)

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 nonbiological areas. Major biological research projects include: 1) development of NMR imaging methods to delineate the "area of risk" following stroke and to assess potential therapeutic intervention, 2) basic research into the origins of NMR signal changes observed in brain following stroke, 3) development of noninvasive methods for measuring tumor oxygenation and evaluating the response of neoplasms to radiotherapy and chemotherapy, and 4) development of NMR spectroscopic and imaging methods to study water movement and structural changes in soft tissues under load. Nonmedical applications include nondestructive testing and characterization of porous media using NMR spectroscopic methods. (Sotak, Helmer)

Ultrasound Measurements
Applications under current investigation at WPI include detection of arteriosclerotic plaque and the examination of skin, 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. Transmission and reflective wave propagation as used to measure tissue and biomaterial elastic properties. (Kohles, Pedersen)

Somatosensory System Analysis
WPI faculty members have developed methods to map the response of single cutaneous receptors to complex spatial-temporal stimuli applied parallel to the skin surface. The ongoing goals of these studies are to apply linear and nonlinear system analysis techniques to the study of general stimulus-coding properties of cutaneous receptors. (Looft)

Biomedical Materials
Calcium Phosphate ceramics for bone substitution. Biocomposites for craniomaxillofacial and orthopedic applications. Shape memory metals and polymers in biomedical devices. Fracture fixation devices. Degradation of implant materials. Interface mechanics issues between soft and hard connective tissues and engineered biomaterials. Structural and biological evaluation of new biomaterials via animal models. (Kohles, Biederman, Shivkumar, Sisson)

Research Facilities

Research projects are conducted in WPI's Salisbury Laboratories as well as at several other on- and off-campus sites. The WPI facilities include the biosensors facility comprised of two laboratories for basic and applied medical optics research, a laboratory for blood gas and animal research, a laboratory dedicated to sensor development and testing, and an in vivo optical imaging laboratory. Other research is carried out in the physiology, medical imaging and electrophysiology laboratories. In addition, there is a small-animal surgery laboratory and animal holding quarters. Mechanical evaluation of tissues and orthopedic constructs are undertaken using servohydraulic test equipment in WPI's Higgins Laboratories.

The research nuclear magnetic resonance (NMR) laboratory is a joint program in magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (MRS) between WPI's Biomedical/ Clinical Engineering Department and the Department of Radiology at the University of Massachusetts Medical Center (UMMC). The 1630-square foot research NMR facility consists of a laboratory for the GE CSI-II 2.0T/45 cm imaging spectrometer, a combined chemistry and electronics laboratory, and two offices. The 8500-square foot clinical MR facility at the adjacent Central Massachusetts Magnetic Imaging Center (CMMIC) accommodates two GE Signa 1.5T clinical units and has offices, conference rooms and a patient reception area.

Close cooperation with UMMC, St. Vincent Hospital and TUSVM makes their staffs and facilities available for thesis projects and internships. Research projects are also available at other affiliated institutions, such as the UMass Memorial Health Care Center.

The Gordon Library provides complete library service, including an extensive microfiche collection, resource videotapes and a computerized literature search service. Access is available to other libraries in the Worcester area, including the University of Massachusetts Medical School library.

Internships

For students in the clinical engineering program, a rotating internship is offered during the year. It includes an orientation period to acquaint the student with general hospital organization and procedures, gives a brief exposure to most of the areas listed below, and is normally required prior to specialized internships.

The specialized internship involves the student full time for approximately one month in ongoing clinical, research or engineering activities, with supervision by WPI faculty and the internship center staff. To assure maximum student involvement and supervision, the number of positions at each internship location listed below is limited.

1.) Biomedical Engineering, Medical Center of Central Massachusetts and UMMS

2.) Cardiovascular Medicine, UMMS Surgery, UMMS

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 (5 years total). However, because a student must still satisfy all graduate degree requirements, the actual time spent in the program may be longer than 5 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.

Degree Requirements

BE 591 — Graduate seminar is a required course every semester for all full-time graduate students.

For the M.S.

A minimum of 30 credit hours is required for the master of science degree, of which at least 6 credit hours must be a thesis. Course requirements include 6 credit hours of life science, 6 credits of biomedical engineering, 6 credits of advanced engineering math and 6 credits of electives (any WPI graduate-level engineering, physics, math, BE, or equivalent course, subject to approval of the department head or the student's academic advisor).

For the M.E.

A minimum of 33 credit hours is required for the master of engineering degree. Course requirements include 6 credits of life science, 12 credits of biomedical engineering, 6 credits of advanced engineering math and 9 credits of electives (any WPI graduate-level engineering, physics, math, BE, or equivalent course, subject to approval of the department head or the student's academic advisor). Students may substitute 3 to 6 credits of directed research for 3 credits of biomedical engineering and/or 3 credits of electives. An internship experience is required for students earning the M.E. in Clinical Engineering (3 credits).

For the Ph.D.

The PhD program has no formal course requirements. However, because research in the field of biomedical engineering requires a solid working knowledge of a broad range of subjects in the life sciences, engineering, and mathematics, course credits must be distributed across the following categories with the noted minimums:

- Biomedical Engineering (12 credits)
- Life Sciences (9 credits)
- Advanced Engineering Mathematics (6 credits)
- Laboratory Rotations (6 credits)
- Responsible Conduct of Science (1 credit)
- Advanced Courses and Electives (12 credits)
- Thesis Research (30 credits)

The student's academic advisory committee may require additional course work to address specific deficiencies in the student's background.

No later than the start of the third year after formal admittance to the PhD program, students are required to pass a PhD Qualifying Examination. This examination is a defense of an original research proposal, outside the area of the student's dissertation topic, made before a committee representative of the area of specialization. The examination is used to evaluate the ability of the student to pose meaningful engineering and scientific questions, to propose experimental methods for answering those questions, and to interpret the validity and significance of probable outcomes of these experiments. It is also used to test a student's comprehension and understanding of their formal coursework in life sciences, biomedical engineering, and mathematics. Admission to candidacy is officially conferred upon students who have completed their course credit requirements, exclusive of thesis research credit, and passed the PhD Qualifying Examination.

Students in the PhD program are required to participate in at least two different laboratory rotations during their first two years in the program. Laboratory rotations - short periods of research experience under the direction of program faculty members - are intended to familiarize students with concepts and techniques in several different engineering and scientific fields. They allow faculty members to observe and evaluate the research aptitudes of students and permit students to evaluate the types of projects that might be developed into dissertation projects. Upon completion of each rotation, the student presents a seminar and written report on the research accomplished. Each rotation is a three- or four-credit course and lasts a minimum of eight weeks if the student participates full time in the laboratory, or up to a full semester if the student takes courses at the same time.

All candidates for the PhD degree must demonstrate teaching skills by preparing, presenting, and evaluating a teaching exercise. This experience may involve a research seminar, lecture, demonstration, or conference in the context of a medical school basic science course. Formal parts of the presentation may be videotaped as appropriate. The presentation and associated materials are critiqued and evaluated by program faculty members. The student's academic advisory committee is responsible for evaluating the teaching exercise based on criteria previously defined. The teaching requirement can be fulfilled at any time and there is no limit to the number of attempts a student may make to fulfill this requirement. It must, however, be completed successfully before the dissertation defense can be held.

The PhD program requires a full-time effort for a minimum of at least three years and does not require a foreign language examination

Admission Requirements

Biomedical engineering embraces the application of engineering to the study of medicine and biology. While the scope of biomedical engineering is broad, applicants are expected to have an undergraduate degree or a strong background in engineering and to achieve basic and advanced knowledge in engineering, life sciences, and biomedical engineering. For the Joint PhD program, students are also expected to have had one semester of organic chemistry, a full year of biology, and mathematics through differential equations. Special programs are available for outstanding graduates lacking the necessary prerequisites or with a background in the physical or life sciences. These special programs typically involve an individualized plan of course work at the advanced undergraduate level, with formal admittance to the program following the successful completion (with grades of "B" or higher) of this course work.

Adjunct Faculty

F. A. Anderson Jr., Research Professor of Surgery; Ph.D., University of Massachusetts Medical School

S. Aronow, Certified Radiological Physicist; Ph.D., Technology in Medicine, Inc.

S. L. Chen, Adjunct Instructor; M.S., New England Medical Center

G. Cho, Senior Vice President; M.S., Cynosure, Inc.

R. Clarke, Professor of Chemistry; Ph.D., Boston University

B. S. Cutler, Professor and Chairman, Division of Vascular Surgery; M.D., University of Massachusetts Medical School

M. A. Davis, Professor of Radiology and Director of Radiologic Research Laboratories; M.D., Sc.D., University of Massachusetts Medical School

R. M. Dunn, Associate Professor, Division of Plastic and Reconstructive Surgery; University of Massachusetts Medical Center

C. L. Feldman, Professor; Sc.D., Brigham and Women's Hospital, Boston

R. M. Giasi , Associate Professor of Anesthesia; M.D., University of Massachusetts Medical School

S. Glick, Research Associate Professor of Nuclear Medicine; Ph.D., University of Massachusetts Medical School

B. Griffin, Chief of Neonatology; M.D., Medical Center of Central Mass.-Memorial

P. Grigg, Professor of Physiology; University of Massachusetts Medical School

J. B. Hermann, Professor, Division of Vascular Surgery; M.D., University of Massachusetts Medical School

A. Karellas, Associate Professor; Ph.D., University of Massachusetts Medical School

M. King, Professor of Radiology; M.D., University of Massachusetts Medical School

M. T. Kirber, Assistant Professor of Psysiology; Ph.D., University of Massachusetts Medical School

P. W. Kotilainen, Production Manager; Ph.D., Hewlett-Packard Co.

M. Leal, Adjunct Instructor; B.S., U.S. Food and Drug Administration

J. P. Lock, Assistant Professor of Medicine; M.D., University of Massachusetts Medical School

G. Majno, Professor of Pathology; M.D., University of Massachusetts Medical School

I. S. Ockene, Professor of Medicine, Director of Preventive Cardiology Program, Associate Director of Cardiovascular Medicine; M.D., University of Massachusetts Medical School

J. A. Paraskos, Professor, Director of Noninvasive Cardiology, Cardiovascular Medicine; Associate Chairman, Department of Medicine; M.D., University of Massachusetts Medical School

N. A. Patwardham, Associate Professor, Division of General Surgery; M.D., University of Massachusetts Medical School

R. F. Rodger, D. V. M., Veterinarian Private Practice

M. J. Rohrer, Assistant Professor of Surgery; University of Massachusetts Medical School

A. Shahnarian, Assistant Professor, Department of Anesthesia; Ph.D., University of Massachusetts Medical School

J. Singer, Professor of Physiology; Ph.D., University of Massachusetts Medical School

T. J. Vandersalm, Professor, Division of Cardiothoracic Surgery; M.D., University of Massachusetts Medical School

J. V. Walsh, Professor of Physiology; M.D., University of Massachusetts Medical School

H. B. Wheeler, Harry M. Haidak Distinguished Professor, Department of Surgery; M.D., University of Massachusetts Medical School

R. P. Zambuto, President; Ph.D., Technology in Medicine, Inc.

Biomedical Sciences

Program of Study

The Worcester Consortium Ph.D. Program in Biomedical Sciences is an innovative program created and administered by WPI's Department of Biology and Biotechnology. The Consortium consists of WPI, Clark University, The University of Massachusetts Medical School, and the Worcester Foundation for Biomedical Research. Students may enter the program and receive their degree either from WPI or from Clark, but may complete their dissertation research at any of the Consortium institutions. Admission to the program requires evidence of substantial postbaccalaureate research experience and a commitment of support from a research sponsor.

Students are expected to begin their dissertation research immediately upon entering the program. Students choosing to enter through WPI are considered WPI graduate students in the Department of Biology and Biotechnology, and must meet the general degree requirements of WPI as well as requirements specified by the Department of Biology and Biotechnology. A detailed description of procedures and degree requirements is available in the department office.

Research Interests

Research opportunities at WPI exist in the general areas of molecular biology and recombinant DNA technology. Other research interests include microbiology, environmental biology, developmental biology, and plant and animal physiology. Details are available upon request.

Combining resources of the four participating institutions presents a unique opportunity for a graduate education. The faculty and laboratories available to the student are magnified over those of any single institution. A professional environment of these dimensions permits a great deal of freedom to acquire and develop many novel ideas during the pursuit of a Ph.D.

Biomedical Sciences Laboratories

The laboratory resources at all four participating institutions are available to aid in the student's research activities, as are graduate-level courses at WPI, Clark University, University of Massachusetts Medical School, and the Worcester Foundation for Biomedical Research.

Registration and Fees

Students may, with the approval of their advisory committee, transfer up to one-third of the required credit hours for the doctoral degree from one of the other consortium institutions or from another accredited institution subject to the following criteria:

- Must be graduate-level courses.
- Research credits are not transferable.
- Grade of B or better.
- Students registering at WPI for research credit at a consortium institution other than WPI are required to pay one-half the current cost per credit hour.
- Course work and research conducted on-campus is charged at the normal credit hour cost.

Degree Requirements

For the Ph.D.

The student's research program is supervised by a committee of professional scientists representing at least two of the participating institutions, including a faculty member from the degree-granting institution. During the first year of study, the student must pass a preliminary examination that includes both written and oral segments. A written dissertation, a seminar based on the content of the dissertation, and a final dissertation defense are also required for the Ph.D. degree. There is no foreign language requirement.

Admission Requirements

A student entering through WPI must meet the entrance and graduation requirements of this institution for the Ph.D. However, the student may have a research advisor and project at University of Massachusetts Medical School, Worcester Foundation for Biomedical Research or WPI. The student is expected to have substantial academic background, surpassing that acquired while pursuing a traditional bachelor's degree in biology, and students with post-graduate experience or a master's degree are encouraged to apply. Research assistant-ships may be offered to qualified students. Teaching assistantships are also available.

Dissertation Defense

Candidates for the Ph.D. must give a public seminar on their dissertation research, to be followed immediately by a defense of the dissertation before an examining committee. The dissertation examining committee should include the student's Advisory Committee. In all cases, the committee must include at least two members of the WPI faculty. For students in the Consortium Ph.D. in Biomedical Sciences, the dissertation examining committee must include at least one member of the Steering Committee of the Consortium. All members of the examining committee must be present for the public presentation and subsequent defense.

The dissertation examining committee will pass the student unanimously or with no more than one dissenting vote. The dissertation will be signed by those members voting for approval. If the student fails the dissertation defense, he/she may repeat the defense within no more than six months from the date of the failed defense. A second failure will result in dismissal from the program.

Requests for more information or application forms should be made to the program director at 508-831-5930, or jbagshaw@wpi.edu.

Program Director

J. C. Bagshaw, Professor and Program Head; Ph.D., University of Tennessee

Program faculty members are assembled as appropriate from WPI, Clark University, University of Massachusetts Medical School and the Worcester Foundation for Biomedical Research.

Chemical Engineering

Programs of Study

Students are given the opportunity to do creative work on state-of-the-art research projects as part of graduate study in chemical engineering. The program offers excellent preparation for rewarding careers in research, industry or education. Selections of graduate courses and thesis projects are made with the aid of a faculty member with whom the student works closely. All graduate students participate in a seminar during each term of residence.

The master's degree program in chemical engineering is concerned with the advanced topics of the field. While specialization is possible, most students are urged to advance their knowledge along a broad front. All students select a portion of their studies from core courses in mathematics, thermodynamics, reactor design, kinetics and catalysis, and transport phenomena. In addition, they choose courses from a wide range of electives. While a master's degree can be obtained for course work alone, most students carry on research terminating in a thesis.

In the doctoral program, a broad knowledge of chemical engineering topics is required for success in the qualifying examinations. Beyond this point, more intensive specialization is achieved in the student's field of research.

Faculty

T.A. Camesano, Assistant Professor; Ph.D., Pennsylvania State University

R. Datta, Professor and Department Head; Ph.D., University of California, Santa Barbara

A. G. Dixon, Professor; Ph.D., University of Edinburgh

Y. H. Ma, Professor Emeritus; Ph.D. Massachusetts Institute of Technology

W. R. Moser, Professor; Ph.D., Massachusetts Institute of Technology

R. W. Thompson, Professor; Ph.D., Iowa State University

R. E. Wagner, Professor Emeritus; Ph.D., Princeton University

A. H. Weiss, Professor Emeritus; Ph.D., University of Pennsylvania

W. M. Clark, Associate Professor; Ph.D., Rice University

D. DiBiasio, Associate Professor; Ph.D., Purdue University

F. H. Ribeiro, Assistant Professor; Ph.D., Stanford University

K. M. McNamara, Assistant Professor; Ph.D., Massachusetts Institute of Technology

B. E. Wyslouzil, Associate Professor; Ph.D., California Institute of Technology

Research Interests

The Chemical Engineering Department's research effort is concentrated in three major areas: Advanced Materials Processing, Biochemical Engineering and Environmental Engineering. Advanced Materials Processing includes catalysis, reaction engineering, zeolite technology, nanostructured materials synthesis, CVD, and SS material characterization.

Biochemical Engineering includes bioreactor engineering and bioseparations. Environmental Engineering encompasses air pollution and atmospheric aerosols, and pollution prevention in chemical processes, environmentally benign chemical reactor technology, and catalysis of waste hydrocarbon removal. Master's and doctoral candidates' research in these areas involves the application of all fundamental aspects of chemical engineering.

Of the 30 graduate students, approximately 75 percent are Ph.D. candidates. Research groups at WPI tend to be small; because of this, students find considerable interaction with faculty advisors as well as among various research groups. In such an atmosphere, graduate students have exceptional opportunities to contribute to the total research effort of their groups. Studies may be pursued in the following areas:

Advanced Materials Processing

Catalysis and Reaction Engineering
Research in this area is centered around the physical and chemical behavior of fluids, especially gases, in contact with homogeneous and heterogeneous catalysts. Projects include diffusion through porous solids, multicomponent adsorption, mechanism studies; synthesis and characterization of catalysts; and heat and mass transfer in catalytic reactors and novel methods for nanometer materials synthesis.

Zeolite Technology
This research continues to focus on the synthesis, modification, characterization and application of zeolite materials. Emphasis recently has been centered on growing large perfect zeolite crystals in high yield for characterization, transport studies, and possible use in membrane materials. Currently, experimentation is under way to explore different synthesis reactor configurations to facilitate growth of crystals.

Chemical Vapor Deposition
In this area, we concentrate on the deposition of inorganic thick and thin films by a variety of CVD techniques. Of particular concern is the development and effects of both intrinsic and thermal stresses. Materials include both pure and composite inorganics.

Solid-State Characterization
The primary focus in this area is the use of optical spectroscopy in the structural characterization of materials, including diamond films, ancient glasses, and archeological materials.

Biochemical Engineering

Bioreactor Engineering: Whole Cells
Research in this area centers around studies of the analysis of biological reactors using whole cells as the biocatalysts. Types of reactors studied include stirred tank, packed bed and hollow fiber, and the types of cells studied are bacteria, yeast and mammalian. The focus of the work is on understanding the behavior of cells in reactor environments. Recently, we have explored the relationship between the stress response and overproduction of recombinant protein products.

Bioreactor Engineering: Plant Tissue Culture
Plants are an important source of pharma-ceutically active compounds. Many of these secondary metabolites are only produced if the plant cells exhibit a certain level of organization, i.e., they exist as plant organs such as roots or shoots. Designing bioreactors to grow plant tissue culture and for micro propagation presents unique engineering challenges. The focus of our work is to understand the response of plant tissue cultures to changes in reactor environment in order to optimize production. This work is a collaborative effort that involves Chemical Engineers, Biologists and Biochemists.

Bioseparations
Full realization of biotechnology's potential to produce useful products will require the engineering of efficient and, in some cases, large-scale production and recovery processes. Research in the bioseparations laboratory is aimed at understanding and exploiting the thermodynamic and transport properties of biological materials underlying their separation to improve existing purification methods and develop new separation techniques. Recent projects include partitioning in aqueous two-phase systems, affinity partitioning, extractive fermentation, filtration using inorganic membranes, and a new large-scale electrophoretic separation method.

Environmental Engineering

Air Pollution and Atmospheric Aerosols
Atmospheric aerosols play a major role in the chemical and radiative processes in the atmosphere. Understanding the formation and growth of new particles in the complex, multicomponent system represented by the atmosphere, is a major challenge. A related issue is the formation of new phases in or on the surface of an existing aerosol, that can influence the chemical reactions occurring there. Experiments and modeling are both used to address these problems.

Environmental Catalysis and Reactor Design
We are interested in using catalysis to solve problems of environmental importance. We are studying new processes that will avoid the production of pollutants and also processes that will recycle undesired products. We work closely with industry to identify the important issues. Nanostructured metal supported catalysts for pollution abatement examine the relationship between particle structure and reactivity. Design of novel reactors to minimize the formation of harmful unwanted side products is carried out, with present emphasis on membrane reactors and preventing thermal runaway in fixed bed reactors.

Fuel Cells
Being considered as clean and efficient power sources for automobiles and stationary appliances. Research is being conducted on developing, characterizing and modeling of fuel cells that are robust for these applications. This includes development of CO Tolerant anodes, higher temperature proton-exchange membranes, and direct methanol fuel cells. In addition, reformers are being investigated to produce H_2O liquid fuels.

Chemical Engineering Laboratories

Bioreactor Engineering Laboratory
This laboratory has stirred-tank, packed-bed and membrane-type bioreactors used in the production of biological products. Sizes range from 1/2 to 15 liters. Facilities also include standard analytical equipment and the use of the magnetic resonance imaging laboratory.

Zeolite Crystallization Laboratory
This laboratory is equipped for hydrothermal syntheses of molecular sieve zeolites over a wide range of temperature, chemical composition and hydrodynamic conditions. The objective is to understand how zeolites nucleate and grow.

Synthesis results are characterized by optical and electron microscopy, X-ray diffraction, and particle size analysis. The unique aspect of measuring zeolite crystal size distribution is facilitated by the computer-interfaced Particle Data Electrozone Celloscope.

Heat and Mass Transfer Laboratory
The experimental capabilities of this laboratory include the measurement of heat and mass transfer coefficients in packed columns. The computational capabilities include two-or three-dimensional simulation of transient or steady-state conduction/diffusion and fluid flow by finite element methods. Computational fluid dynamics and simulation of heat and mass transfer mechanisms are used to investigate fundamental phenomena in chemical reactors.

Plant Tissue Culture Laboratory
This laboratory includes plant culture rooms, analytical equipment to monitor the composition of the liquid and gas phases of the reactors and to analyze for the desired secondary products.

Aerosol Laboratory
This laboratory is equipped to conduct fundamental studies of aerosol formation, growth and structure. We have both a two pulse expansion cloud chamber and a supersonic nozzle so that we can examine a wide range of supersaturations. The supersonic nozzle is portable and is regularly transported to the Cold Neutron Research Facility at the National Institute of Standards and Technology to conduct Small Angle Neutron Scattering experiments on nanodroplet aerosols.

CVD Laboratory
This lab is equipped with a state-of-the-art high power microwave CVD unit capable of operation over a wide range of conditions. In addition, several small thermal CVD systems are available. These are used to study growth processes for inorganic materials.

Catalytic Laboratory
This laboratory is equipped with several high-velocity hoods to ensure safe operation of high-pressure experiments. High temperature processing ovens, specialized high-pressure reactors, and aerosol processing equipment supports the synthesis of novel ceramic and catalytic materials. Two Fourier-Transform infrared spectrometers are equipped with optical fiber and cylindrical internal reflectance reactors for in situ spectroscopic studies.

Analytical and process equipment used for adsorption and catalytic reaction studies is available in the laboratory. This includes a duPont 21-492 double focusing mass spectrometer, 10 gas chromatographs with TC, FID, EC, and radioactivity detectors, and duPont TGA and DSC instruments. Reactors include pulse and flow tubular systems, fixed and fluid bed reactors, and operate at atmospheric and high pressures. There is also a computerized multi-step batch reaction system for synthesis of single-strand DNA.

Environmental Catalysis Laboratory
We are equipped for studies on model and high surface area catalysts. The model catalysts (foil or single crystals) are studied on a PHI model 60 ultra-high vacuum (UHV) chamber equipped with Auger electron spectroscopy, x-ray photoelectron spectroscopy, UTI 100C mass spectrometer, and low energy electron diffraction (Varian). The model catalyst can be prepared and characterized under UHV and then transferred under UHV to a batch reactor through a metal bellows transfer arm. Reaction rates can be measured in the batch reactor at the same reaction conditions employed on high surface areas.

To study high surface area catalysts we have batch, CSTR, and flow reactors for the measurement of rates. A system for the measurement of metal and total surface area is also available. A flow reactor attached to a mass spectrometer (HP 5988A GC-MS) is used for temperature reaction experiments.

An ultraviolet Raman spectrometer is available for spectroscopic studies of samples under reaction conditions. This spectrometer avoids fluorescence from carbon containing samples and also background radiation (luminescence) in high temperature reactions.

Catalyst and Reaction Engineering Laboratory and Fuel Cell Laboratory
(Description- (see attachment for details)

Center for Inorganic Membrane Studies
The goals of the Center for Inorganic Membrane Studies are to develop industry and university collaboration for inorganic membrane research, and to promote and expand the science of inorganic membranes as a technological base for industrial applications through fundamental research. An interdisciplinary approach has been taken by the center to assemble all of the essential skills in synthesis, modeling, material characterization, diffusion measurements and general properties determinations of inorganic membranes. Current projects include microporous and dense inorganic membrane synthesis, and reactive membrane studies, fouling and transport studies, characterization of membrane degradation, applications in biotechnology. Facilities including SEM, TEM, NMR and ultrafiltration units are available.

Adsorption and Diffusion Laboratory
This laboratory has modern facilities to study the adsorption and diffusion of gases and vapors in porous materials such as zeolites, molecular sieve carbons, porous alumina, pillared clays, and hollow fiber inorganic membranes. Two Cahn electrobalances are available for pure gas adsorption and diffusion studies. A well-stirred unit equipped with a Hewlett-Packard 5970 MSD Mass Spectrometer is available to study gas mixture adsorption and diffusion in porous materials at both low and high pressures.

Degree Requirements

For the M.S.

Thesis Option
A total of 30 credit hours is required including 18 credit hours of course work and at least 12 credit hours of thesis work. The course work must include 15 credit hours of graduate level Chemical Engineering courses and 9 of these must be chosen from the core curriculum. A satisfactory oral seminar presentation must be given every year in residence.

Non-Thesis Option

A total of 30 credit hours is required including a minimum of 24 credit hours in graduate level courses. At least 21 course credit hours must be in Chemical Engineering and 9 of these must be chosen from the core curriculum. A maximum of 6 credit hours of independent study under the faculty advisor may be part of the program.

For the Ph.D.

There are no language requirements, although candidates are encouraged to be familiar with those languages in which a significant portion of their specialized field is published.

Upon completion of the comprehensive qualifying examination, candidates must present a research proposition in order to acquaint members of the faculty with the chosen research topic.

Admission Requirements

An undergraduate degree in chemical engineering is preferred for master's degree applicants. However, those with related backgrounds will also be considered, but may be required to complete prerequisite coursework in some areas.

Chemistry & Biochemistry

Programs of Study

Because graduate education in chemistry and biochemistry is primarily research-oriented, there are no formal departmental course requirements in the graduate program. However, it is expected that each graduate student will take graduate-level courses in areas of chemistry that are relevant to their field of specialization. Entering students who have deficiencies in specific areas of chemistry (inorganic, organic, physical), as revealed by preliminary examinations, take appropriate courses to correct these deficiencies.

Each student should select a research advisor no later than the end of the first term (seven weeks) of residence, and research should be started by the beginning of the second term. At the end of the first semester of the second year of residence, the student must submit a written and an oral progress report on research completed to the Chemistry/Biochemistry Department. A committee of three faculty members, including the research advisor, will consider this progress report and the student's performance in courses, and will recommend to the department whether the student should complete a master of science degree or that the student be formally admitted to the Ph.D. program.

Research Interests

Chemistry and biochemistry faculty members pursue research programs in a variety of areas of inorganic, organic, biological and physical chemistry. Their diverse ongoing projects include, but are not limited to, synthesis of medicinally important compounds; protein chemical modification; protein structure/function relationships; nucleic acid/protein interactions; biochemistry of plant pathogen interactions: enzyme structure and mechanism; photochemistry on zeolites; phototransposition chemistry of heteroaromatic compounds; photochemistry and photophysics of reactive intermediates; two-laser flash photolysis; intramolecular energy and charge transfer in large molecules and biomolecules; molecular scale devices; photomedicine; matrix isolation studies of reactive intermediates; photophysical properties of cumulenes; low-temperature photochemistry and spectroscopy of heterocyclic molecules; and molecular modeling of photochemical reactions.

Faculty

J. P. Dittami, Associate Professor and Head; Ph.D., Rensselaer Polytechnic Institute

H. Beall, Professor; Ph.D., Harvard University

L. H. Berka, Professor; Ph.D., University of Connecticut

R. E. Connors, Professor; Ph.D., Northeastern University

N. K. Kildahl, Professor; Ph.D., University of Illinois

W. G. McGimpsey, Professor; Ph.D., Queen's University

J. W. Pavlik, Professor; Ph.D., George Washington University

A. A. Scala, Professor; Ph.D., Polytechnic Institute of Brooklyn

S. J. Weininger, Professor; Ph.D., University of Pennsylvania

W. D. Hobey, Associate Professor; Ph.D., California Institute of Technology

J. M. Argüello, Assistant Professor; Ph.D., Universidad Nacional de Rió Cuarto, Argentina

K. K. Wobbe, Assistant Professor; Ph.D., Harvard University

Chemistry and Biochemistry Laboratories

The Chemistry/Biochemistry Department is located in Goddard Hall, which houses 20,000 square feet of research laboratories, shops and instrument laboratories. The research activities in the department are concentrated in the following areas: organic synthesis; medicinal chemistry; biochemistry; laser chemistry; photochemistry; inorganic synthesis; solid state chemistry and molecular modeling. Department facilities and instrumentation in individual research laboratories that support this research include 200 and 400 MHz FT-NMR, GC-MS, GC, HPLC, FT-IR, UV-VIS absorption, florescence and phosphorescence; and cyclic voltammetry. The department is exceptionally well set-up with computer facilities with a large number of workstations, pentium PCs and Macintosh Power PCs and is also networked to the college's mainframe. The Laser Laboratory is equipped with several nanosecond pulsed laser sources including excimer, Nd/YAG and flashlamp-pumped dye lasers and time-resolved detection equipment that includes both transient digitizers and an Optical Multichannel Analyzer. The Biochemistry Laboratory is the newest facility and represents a major commitment and emphasis of the department. The newly renovated research space includes a cold room and a plant growth chamber and state-of-the-art equipment such as PCR, liquid scintillation counter, centrifuges, microfuges, tissue culture facilities, UV crosslinker and DNA sequencer.

Degree Requirements

For the M.S.

Thesis

The M.S. degree in chemistry or biochemistry requires 30 semester hours of credit of which at least 6 or more must be thesis research, the remainder in approved independent studies and courses at the 4000 or 500 level. Special requirements of the Chemistry/Biochemistry Department are that an M.S. candidate must submit a thesis based upon research conducted under the direction of a faculty member during his or her tenure at WPI. The thesis must be approved by the faculty advisor and the chairman of the Chemistry/Biochemistry Department.

For the Ph.D.

Cumulative Examinations

After formal admission to the doctoral program, Ph.D. candidates must take the cumulative examinations in their field of specialization. These examinations are given eight times a year, and a passing grade in six examinations completes the cumulative requirement; this must be attained in the first 12 examinations taken if the student is to continue for the Ph.D. degree.

Dissertation

An oral examination is held after candidates have submitted their dissertations. The faculty of the Chemistry/Biochemistry Department, at least one member of another department, and other scientists are invited to participate. The examination generally consists of a brief oral presentation of the principal points of the dissertation by the candidate, followed by questions from the faculty. The scope of the examination may be broadened if the faculty feel it necessary. In addition, the candidate is required to present as a part of the thesis and examination an original, significant proposal for further research in the area. Students formally admitted to the Ph.D. program are expected to complete their cumulative examinations within three semesters (not including summers) from their admission date. At that time students should apply to the department for Ph.D. candidacy status.

Admission Requirements

A B.S. degree with demonstrated proficiency in chemistry or biochemistry is required to enter the M.S. program. Students wishing to pursue the Ph.D. must follow the procedure described above.

Civil & Environmental Engineering

Programs of Study

The department of civil and environmental engineering offers graduate programs leading to the degrees of master of science, master of engineering, doctor of philosophy. The department also offers graduate and advanced certificate programs. Full- and part-time study is available.

Master of Science and Doctor of Philosophy

The master of science and doctor of philosophy in civil and environmental engineering are arranged to meet the interests and objectives of the individual student. Through consultation with an advisor, appropriate selection from the courses listed in this catalog, from 4000-level undergraduate courses suitable for graduate credit, independent graduate study, and by concentrated effort in a research or project activity, a well planned program may be achieved. Students may take acceptable courses in other departments. The complete program must be approved by the student's advisor and the Graduate Program Committee.

The department strengths in terms of faculty interests and research activities, together with related offerings within the department at WPI and consortium colleges, provide a wide range of opportunities for specialized study. Specialty programs are available in the following areas:

Structural Engineering

Courses from the structural offerings, combined with appropriate mathematics, mechanics and other courses, provide opportunities to pursue programs ranging from theoretical mechanics and analysis to structural design and materials research. There are ample opportunities for research and project work in mechanics, structures and construction utilizing campus facilities and in cooperation with area consulting and contracting firms. The integration of design and construction into a cohesive master builder plan of studies is available.

The research topics in the recent past as UPI are as follows — Three dimensional dynamic response of tall buildings to stochastic winds, the inelastic dynamic response of tall buildings to earthquakes, response of braced, framed-tube and outrigger braced tall buildings to wind, dynamic response of tall buildings with base-isolation to seismic loads, eccentrically braced tall buildings to resist earthquakes, approximate methods of analysis and preliminary design of tall buildings, knowledge based systems and neural networks for tall building design, structural design agents for building design, finite element methods for nonlinear analysis, finite element analysis of shell structures for dynamic and instability analysis, and box girder bridges.

Environmental Infrastructure

Environmental engineers are required to understand a number of technical fields and must be able to effectively manage projects involving complex managerial and regulatory issues. The CEE department has developed graduate degree programs to satisfy a broad range of student needs and interests and to provide students with this technical managerial expertise. Graduate environmental opportunities are categorized as focus areas in water quality systems and waste remediation systems.

Water Quality Systems — emphasizes the quality of water in natural systems along with the development and design of water and wastewater treatment systems that will serve to protect the environment.

Waste Remediation Systems — focuses on the containment, prevention, and remediation of soil and groundwater contaminated by industrial and hazardous wastes. This focus area includes the modeling and experimental investigation of contaminant fate and transport in the natural environment.

These two focus areas have been developed to incorporate a wide range of issues that exist today and are anticipated to exist into the future. Our objectives for the environmental programs are to:

- provide graduate educational opportunities for all qualified students, do our best to make access to graduate education as convenient as possible,
- provide an interactive educational process and use this program as a basis to maintain our close linkages and collaborations with the professional community.

Current research efforts provide project opportunities in environmental fluid dynamics, protection and management of water resources, groundwater flow and contaminant transport in groundwater, remediation and treatment of contaminated groundwater, water distribution and treatment, treatment of industrial and hazardous wastes, pollution prevention, and in other related areas. Additional project opportunities are provided through collaborative research projects with Alden Research Laboratory, an independent hydraulics research laboratory with large-scale experimental facilities.

Geotechnical Engineering
Course offerings in earth sciences, soil mechanics and foundation engineering may be combined with structural engineering and engineering mechanics courses as well as other appropriate college offerings.

Engineering and Construction
Designed to assist the development of professionals knowledgeable in the design/construction engineering processes, labor and legal relations, and the organization and use of capital. The program has been developed for those students interested in the development and construction of large-scale facilities. The program includes two required courses: CE 580 and MG 501. MG 501 can be substituted by an equivalent 3 credit hour course approved by department. It must also include any three of the following courses: CE 581, CE 582, CE 583, CE 584, CE 585, CE 586. The remaining courses in the students program includes a balanced choice from other civil engineering and management courses as approved by the advisor. It is possible to integrate a program in design and construction to develop a cohesive master builder plan of studies. Active areas of research include Integration of Design and Construction, Models and Information Technology, Cooperative Agreements, and International Construction.

Highway Infrastructure
The objective of the Highway Infrastructure Program is to provide a center for learning and education for the engineers who will design, build and maintain tomorrow's highway infrastructure.

The Highway Infrastructure Program is a multi-disciplinary interdepartmental program designed to prepare students for careers designing, maintaining and managing highway infrastructure systems. Students gain proficiency in highway infrastructure technology in two complimentary ways: projects and course work. Projects focus on developing improved practical methods, procedures and techniques. Course work is focused on practical aspects of infrastructure technology needed by practicing engineers.

Research in the Highway Infrastructure Program is sponsored by a variety of private and governmental organizations including the U. S. Federal Highway Administration, the National Cooperative Highway Research Program, the Massachusetts Highway Department, The Maine Department of Transportation, the Iowa Department of Transportation, the New England Transportation Consortium, the National Science Foundation and others. Some of the more active research areas being pursued in the Highway Infrastructure program include developing side impact crash test and evaluation procedures, developing procedures for performing in-service performance evaluations of traffic barriers, assessing the field performance of traffic barriers, finite element analysis of crash events, structural crashworthiness, Superpave technology, pavement smoothness and ride quality measurement, recycled asphalt materials, and implementation of innovation in transportation management and other transportation related topics.

Interdisciplinary M.S. Program in Construction Project Management
Combines offerings from several disciplines including civil engineering, management science, business and economics. Requirements for the degree are similar to those listed above for the master of science. engineering and construction management program.

Master of Engineering

The master of engineering is a professional practice-oriented degree. The degree is available both for undergraduate students who wish to remain at WPI an additional year to obtain both a bachelor of science and a master of engineering as well as for students possessing a B.S. degree who wish to enroll in graduate school to seek this degree. At present, the M.Eng. program is offered in the following three areas of concentration:

Master Builder
The Master Builder Program is designed for engineering and construction professionals who wish to better understand the industry's complex decision-making environment and to accelerate their career paths as effective project team leaders.

This is a practice oriented program that builds upon a project-based curriculum and uses a multi-disciplinary approach to problem solving for the integration of planning, design, construction and facility management. It emphasizes hands-on experience with information technology and teamwork.

Environmental
The Environmental Master of Engineering program concentrates on the collection, storage, treatment, and distribution of industrial and municipal water resources, and on pollution prevention and the treatment and disposal of industrial and municipal wastes.

Civil and Environmental Engineering Laboratories

The department has three civil and environmental engineering laboratories (Environmental Lab, Geotechnical Lab,and Materials/Structural Lab) plus three computer laboratories (Lab 1, Lab 2, and Lab 3) located within Kaven Hall. The civil and environmental engineering laboratories are used by all civil and environmental engineering students and faculty. The computer laboratories are open to all WPI students and faculty. Uses for all six laboratories include formal classes, student projects, research projects and unsupervised student activities.

Fuller Environmental Laboratory
The Fuller Laboratory is designed for standard water and wastewater analysis. Testing capabilities are physical measurements (solids, turbidity, color, etc.), chemical measurements (nutrients, metals, BOD, COD, etc.) and biological measurements (Total Plate Count, Coliform, Yeast, etc.). Major equipment includes heaters, incubators, furnaces, spectrophotometers, Hach Kits, reflux equipment, balances, DO meters, pH meters, specific ion meters, de-mineralization apparatus, and various specialty measurement devices. Bench space is available for research projects (treatability studies, soil/contaminant studies, and various experiments). Primary use for this facility is the Environmental Engineering Laboratory course (CE 4060), MQP projects and graduate student research experiments.

Materials/Structural Laboratory
The Materials/Structural Laboratory is a setup for materials and structures testing. The laboratory is utilized for undergraduate teaching and projects and graduate research. The primary use of the laboratory is teaching CE 3026.

Research activities include construction materials processing and testing. The laboratory is equipped for construction materials processing and mechanical testing. Construction materials processing includes portland cement concrete, asphalt concrete, fiber composites, etc.

Geotechnical Laboratory
The Geotechnical Laboratory is equipped for soil testing and is utilized for undergraduate teaching and projects and graduate research. The primary use of the laboratory is teaching CE 4046.

Computer Laboratory No. 1
This laboratory contains 25 pentium computers connected to WPI's Novell and UNIX network system. The facility has a complete presentation system (computer projector, VCR, sound system). Primary use of this laboratory includes math courses, the civil and environmental engineering introductory course (CE 1030), civil and environmental engineering project work (MQP and AutoCad course projects) and open use by the WPI Community.

Computer Laboratory No. 2
This laboratory contains 25 pentium computers connected to WPI's Novell and UNIX network system. In addition, hook-up jacks to network connections for laptop computers are also provided. A complete presentation system (computer projector, VCR, sound system) is in this facility. Primary use of this laboratory is management courses, civil and environmental engineering courses and group project work.

Computer Laboratory No. 3
This laboratory contains three M-Pro dual processor computers and five pentium computers. Primary use of this laboratory is for highway impact simulation studies.

Degree Requirements

For the M.S.
The completion of 30 semester hours of credit, of which 6 credits must be research or project work is required. A non-thesis alternative consisting of 33 semester hours is also available. In addition to civil and environmental engineering courses, students also may take courses relevant to their major area from other departments. Students who do not have the appropriate undergraduate background for the graduate courses in their program may be required to supplement the 30 semester hours with additional undergraduate studies.

For the M.Eng.
The master of engineering degree requires the completion of an integrated program of study that is formulated with a CEE faculty advisor at the start of the course of study. The program and subsequent modifications thereof must be submitted to and approved by the CEE department head or the graduate program coordinator when they are developed or changed. The program requires the completion of 30 semester hours of credit. The following activities must be fulfilled through completion of the courses noted or by appropriate documentation by the department head or graduate program coordinator: experience with complex project management (CE 593 Advanced Study Project), competence in integration of computer applications and information technology (CE 585 Technology in the Integration of Civil Engineering), and knowledge in the area of professional business practices and ethics (CE 501 Professional Practice). The program shall also include coursework in at least two subfields of civil and environmental engineering that are related to the M.Eng. area of specialization.

The primary subfield will provide the student with competence required for the analysis of problems encountered in practice and the design of engineering processes, systems and facilities. Subfields are currently available in structural engineering, engineering and construction management, highway and transportation engineering, geotechnical engineering, materials engineering, geohydrology, water quality management, water resources, and waste management. The subfield requirements are satisfied by completing two thematically related graduate courses that have been agreed upon by both the student and the advisor as appropriate to the program of study. In addition to the subfields noted above, other appropriate areas may be identified as long as it is clear that the courses represent advanced work and compliment the program. Coursework and other academic experiences to fulfill this requirement will be defined in the integrated plan of study at the start of the program.

Transfer Between M.S. and M. Eng. Program
Generally, students are able to complete the M.S. and M.Eng. degree requirements in two to three years of part-time study. A student may transfer from the M.Eng. program to the M.S. program at any time. A student may transfer from the M.S. program to the M.Eng. program only after an integrated program of study has been agreed upon by the student and the advisor in the area of concentration and approved by the CEE department head or the graduate program coordinator.

For the Ph.D.
A dissertation in the candidate's major field of study is required. It is through the dissertation that a student demonstrates the ability to work independently on complex problems at a level commensurate with the Ph.D. degree. Since research interests of the civil and environmental engineering faculty are varied, there is opportunity for conducting research in several areas.

In addition to the college requirements for the Ph.D. degree, special requirements of the Civil and Environmental Engineering Department include the following: minor requirement comprehensive examination. Students must establish a minor outside their major area. This may be accomplished with three courses in the approved minor area. One member of the student supervisory committee should represent the minor area. The student supervisory committee has the authority to make decisions on academic matters associated with the candidates Ph.D. program. To become a candidate for the doctorate, the student must pass a comprehensive examination administered by the student supervisory committee. The candidate on completion and submission of the dissertation must defend it to the satisfaction of the supervisory committee.

Admission Requirements

For the M.S.
A B.S. degree in civil engineering (or another acceptable engineering field) is required for admission to the M.S. program in civil engineering. Students who do not have an ABET accredited B.S. degree may wish to enroll in the inderdisciplinary M.S. program

For the environmental engineering program, a B.S. degree in civil, chemical or mechanical engineering is normally required; however, students with a B.S. in other engineering disciplines as well as physical and life sciences are eligible, provided they have met the undergraduate math and science requirements of the civil and environmental engineering program. As a minimum, a course in the area of fluid mechanics is also required. All graduates of this option will receive a master of science in environmental engineering. Students with a B.S. in civil engineering may petition the department Graduate Program Committee to change the degree designation to an M.S. in civil engineering, if they so desire, and are qualified.

For the interdisciplinary M.S. program in construction project management students with a degree in architecture, management engineering, etc. are normally accepted to this program. Management engineering students may be required to complete up to one year of undergraduate civil engineering courses before working on the M.S.

For the M.Eng.
A B.S. degree in civil engineering (or another acceptable engineering field) is required for ad-mission to the M.Eng. program in civil engineering.

For the Ph.D.
Ph.D. applicants must have earned a master's degree (at WPI or another acceptable school) and passed a qualifying admission examination. This examination will ordinarily be administered within the first eighteen credits of registration in the Ph.D. program.

Faculty

F. L. Hart, Professor and Head; Ph.D., University of Connecticut

T. El-Korchi, Professor; Ph.D., University of New Hampshire

R. W. Fitzgerald, Professor; Ph.D., University of Connecticut

J. C. O'Shaughnessy, Professor; Ph.D., Pennsylvania State University

L. D. Albano, Associate Professor; Ph.D., Massachusetts Institute of Technology

R. A. D'Andrea, Associate Professor; Ph.D., Cornell University

M. S. FitzPatrick, Associate Professor of Urban and Environmental Planning; Ph.D., Harvard University

P. Jayachandran, Associate Professor; Ph.D., University of Wisconsin

P. P. Mathisen, Assistant Professor; Ph.D., Massachusetts Institute of Technology

R. Pietroforte, Assistant Professor; Ph.D., Massachusetts Institute of Technology

M. H. Ray, Associate Professor & White Chair; Ph.D., Vanderbilt University

G. F. Salazar, Associate Professor; Ph.D., Massachusetts Institute of Technology

R. B. Mallick, Assistant Professor; Ph.D., Auburn University

R. K. Allen, Adjunct Associate Professor; J.D., Franklin Pierce Law Center

D. N. Brocard, Adjunct Associate Professor; Ph.D., Massachusetts Institute of Technology

A. G. Ferron, Adjunct Associate Professor; B.S., WPI

F. Mulligan, Adjunct Professor; Ph.D., Harvard University Associate Professor

M. Padmanabhan, Adjunct Associate Professor; Ph.D., Georgia Institute of Technology

J. K. Wakely, Adjunct Associate Professor; M.S., University of Maine

N. Wittels, Adjunct Research Associate Professor; Ph.D., Massachusetts Institute of Technology

Computer and Communications Network

Program of Study

A specialization in computer and communications networks is available within the master's degree programs of the computer science and the electrical and computer engineering departments.

Students enrolled in this specialization will receive the Master of Science Degree in Computer Science or Electrical and Computer Engineering, with a notation on their transcript "Specialization in Computer and Communications Networks." The program is focused on preparing students for professional positions in industry, but the education also provides excellent preparation for Ph.D. study in networks.

This program prepares graduates for technical leadership positions in the design and implementation of computer and communications networks, including local and wide-area computer networking, distributed computation, telecommunications (including voice, data, and video services), wireless networking, and personal mobile communications. All of the fundamental hardware and software aspects of networks will be treated in the program:

1. The seven layers of the ISO network model;
2. Transmission media and terminals (including fiber optics, cable, and radio);
3. Switching and routing methods (including packet switching);
4. Systems modeling and performance analysis;
5. Methods of distributed computation;
6. Current and evolving standards and protocols;
7. Impacts of the information type (voice, video, text, etc.) on optimal transmission and routing methods.

An accelerated part-time option is available with cooperating corporations, with completion in two years.

Faculty

This is a joint specialization taught by computer science and electrical and computer engineering faculty.

CCN Project

Each student in the CCN Specialization must complete an in-depth project demonstrating the ability to apply and extend the material studied in their coursework. Students have the option of completing a practice-oriented internship or a research-oriented thesis.

The internship is a high-level network engineering experience, tailored to the specific interests and background of the student. Each internship is carried out in cooperation with a sponsoring organization, and must be approved and advised by a WPI faculty member in the CS or ECE Department. Internships may be proposed by a faculty member, by an off-campus sponsor, or by the student. The internship must include proposal, design, and documentation phases, and generally includes implementation and testing. The student will prepare a report describing the internship activities, and will make a presentation before a committee including the faculty advisor and a representative of the sponsoring organization. Internship examples include transceiver design for new media, security and encryption protocols, protocol converters, databases to support efficient routing, and network system designs for specific environments.

The thesis option for the CCN project is a research-oriented experience in an area of current research in an area of computer and communications networks. The thesis must be pursued under the direction of a WPI faculty member in the CS or ECE Department. The result of the thesis is a thesis document, describing the results of the research, and a public presentation.

Degree Requirements

Computer Science: 33 credits
Electrical and Computer Engineering: 33 credits for non-thesis; 30 credits for thesis.

Required Courses
(4 courses, 12 credits):
Analysis of Probabilistic Signals and Systems or Analysis of Computations and Systems (EE 502 or CS 504)

Introduction to Local and Wide Area Networks (CS 513/EE 506)

and two of the following courses:
Telecommunications Transmission Technologies (EE 535)

High Performance Networks (CS 530/EE 530)

Advanced Computer and Communications Networks (EE 537/CS 577)

Modeling and Performance Evaluation of Networks and Computer Systems (CS 533/EE 581)

Elective Courses
(at least three from list):
Digital Communications: Modulation and Coding (EE 532)

Advances in Digital Communication (EE 533)

Multiple Processor and Distributed Systems (EE 575/CS 515)

Advanced Operating System Theory (CS 535)

Design of Software Systems (CS 509)

Wireless Information Networks (EE 538)

Cryptography and Data Security (CS 578/EE 578)

Advanced Cryptography (EE 579R)

Telecommunication Policy (EE 508)

Mobile Data Networking (EE 539S/CS 525W)

Any of the courses EE 535, EE 530/CS530, EE 537/CS 577, and CS 533/EE 581 not taken to satisfy the required courses above.

CCN Project
The student must complete one of the following:

1. CCN Internship (EE 595/CS 595) 6 credits
   This project requirement may be waived with documentation of relevant industrial experience. The waiver must be approved by the Graduate Program Committee of the student's department in consultation with the CCN Director. If this requirement is waived, the student must take two additional courses from the list of elective courses above, or two additional courses approved by the department's Graduate Program Committee.
2. Master's thesis in the area of computer and communications networks (9 credits)

Free Electives
To bring total to 33 credits, or 30 credits for students in the ECE Department completing a master's thesis. Courses may be chosen from relevant graduate-level courses in computer science, electrical and computer engineering, mathematics, or management. Some students in the computer science degree program will need to use these electives to satisfy the area requirements for the CS master's degree program.

Important Note – Since the CCN Specialization is a specialization in the master's programs of the Computer Science and Electrical and Computer Engineering Departments, students in the CCN Specialization must also satisfy all requirements of whichever of the Computer Science or Electrical and Computer Engineering master's program they are enrolled in.

Admission Requirements

The program is conducted at an advanced technical level, and requires, in addition to the WPI admissions requirements, a solid background in EE and/or CS. Normally a B.S. degree in EE or CS is expected; however, applicants with comparable backgrounds, together with expertise gained through work experience, will also be considered. Admission is highly selective, and decisions will be based both on previous academic performance and on relevant technical experience. Admission decisions are made by the department to which the student applies.

Computer Science

Programs of Study

The graduate program in computer science provides a foundation in the advanced areas of computer science. Course work includes the theory, design, analysis and application of computer software and hardware. Although the graduate degrees are designed to provide a strong foundation in general computer science, students may concentrate on courses outside of the core in a particular area of computer science. Both master of science and doctor of philosophy degrees are available.

The program is flexible, designed for both the recent graduate and the working professional. The same teaching staff, courses and high standards apply to both versions of the graduate program.

Faculty

M. Hofri, Professor and Dept. Head; D.Sc., Technion-ITT, Haifa, Israel

D. C. Brown, Professor; Ph.D., Ohio State University

D. Finkel, Professor; Ph.D., University of Chicago

S. M. Selkow , Professor; Ph.D., University of Pennsylvania

L. A. Becker, Associate Professor; Ph.D., University of Illinois

M. A. Gennert, Associate Professor; Sc.D., Massachusetts Institute of Technology

N. I. Hachem, Associate Professor; Ph.D., Syracuse University

R. E. Kinicki, Associate Professor; Ph.D., Duke University

K. A. Lemone, Associate Professor; Ph.D., Northeastern University

E. A. Rundensteiner, Associate Professor; Ph.D., University of California at Irvine

M. O. Ward, Professor; Ph.D., University of Connecticut

C. E. Wills, Associate Professor; Ph.D., Purdue University

I. F. Cruz, Assistant Professor; Ph.D., University of Toronto

G. T. Heineman, Assistant Professor; Ph.D., Columbia University

C. Ruiz, Assistant Professor; Ph.D., University of Maryland

G. N. Sarkozy, Assistant Professor; Ph.D., Rutgers University

M. L. Claypool, Assistant Professor; Ph.D., University of Minnesota

M. R. Stevens, Assistant Professor; Ph.D., Colorado State University

Research Interests

The current departmental activities include among other areas artificial intelligence, computer vision, computer graphics, database and information systems, distributed systems, graph theory and computational complexity, network performance evaluation, software engineering, visualization, and web-based systems. Research groups meet weekly and focus on topics related to the above areas. Students are encouraged to participate in these meetings related to their area(s) of interest. Research and development projects and theses are available in these areas. Computer science students may also participate in computer applications research work being conducted in a number of other departments including electrical and computer engineering, mechanical engineering, biomedical/clinical engineering, fire protection engineering, and at Alden Research Laboratories. Students are also encouraged to undertake projects and theses in cooperation with neighboring computer manufacturers or commercial organizations.

Computer Science Laboratories

The Computer Science Department has a number of laboratories equipped respectively with state-of-the-art machines, ranging from SGI machines to NT servers, housing respective research groups. These include artificial intelligence lab, performance evaluation and distributed systems lab, the database base systems lab, the software engineering lab, the advanced information systems lab, and the visualization lab as well as several Undergraduate Project labs, and a Graduate Project lab. WPI's academic programs are supported by a large array of powerful computer facilities, including DEC Alpha, SPARC-Solaris, SGI and Sun machines, as well as numerous PCs, terminals and workstations.

Off-Campus Research Opportunities

Computer science graduate students have opportunities for research and development in cooperation with several neighboring organizations, both for master's thesis as well as Ph.D. dissertation. These and other opportunities provide real-world problems and experiences consistent with WPI's policy of extending learning beyond the classroom.

In addition, summer employment is often available at many local industries.

Degree Requirements

For the M.S.

These degree requirements are effective for all students matriculating after July 1, 1991. Those students who matriculated prior to this date may choose to use the degree requirements stated in the graduate catalog effective at the time of matriculation. The student may choose between two options to obtain the master's degree: thesis or course work. Each student should carefully weigh the pros and cons of each alternative in consultation with his or her advisor prior to selecting an option, typically in the second year of study. The department will allow a student to change options only once.

Thesis Option

At least 33 credit hours including the thesis must be satisfactorily completed. A thesis consisting of a research or development project worth a minimum of 9 credit hours must be completed and presented to the faculty. A thesis proposal must be approved by the department by the end of the semester in which a student has registered for a third thesis credit. Proposals will be considered only at regularly scheduled department meetings. The 33 credit hours must include at least one course from each of the core areas. Students should endeavor to take these required four courses as early as possible so as to provide the background for the remaining graduate work. The remaining courses may, with prior approval of the student's advisor, consist of computer science courses, independent study, or courses elected from other disciplines. At most, two courses in other disciplines will be accepted.

Course Work Option

A total of at least 33 credit hours must be satisfactorily completed, including at least one course from each of the core areas. Students should endeavor to take these required courses as early as possible so as to provide the background for the remaining graduate work. The remaining seven courses may, with prior approval of the student's advisor, consist of computer science courses, independent study, or up to two courses elected from other disciplines.

To obtain a master's degree all students must demonstrate graduate level competence in the following core areas of computer science. To satisfy each core area requirement the student must satisfactorily complete at least one of the courses given in each core area. Students may petition the department to waive any core area requirement under special circumstances, but such action is strongly discouraged.

Theory
CS 503 Foundations of Computer Science
CS 553 Theory of Computability
CS 559 Advanced Topics in Theoretical Computer Science Analysis

Analysis
CS 504 Analysis of Computations and Systems Design

Design
CS 509 Design of Software Systems
CS 536 Programming Language Design Systems

Systems
CS 502 Operating Systems
CS 513 Introduction to Local and Wide Area Networks
CS 533 Modeling and Performance Evaluation of Network and Computer Systems
CS 535 Advanced Topics in Operating Systems

The department will accept at most 9 credit hours of transfer credit from other graduate programs. If appropriate, this transferred credit may be used to satisfy core area requirements.

Students funded by a teaching assistantship, research assistantship, or fellowship must complete the thesis option.

For the Ph.D.

Students are advised to contact the department for detailed rules, as there are departmental guidelines, in addition to the Institute's requirements, for the Ph.D. degree.

Upon admission, the student is assigned an academic advisor and together they design a plan of study during the first semester of the student's Ph.D. program.

The student must take and perform acceptably on the Ph.D. qualifying examination which includes both a written examination and a research component. Application to take the examination should be submitted to the department secretary at least two months prior to the examination date. The Ph.D. student is required to pass the examination prior to completing 36 Ph.D. credits.

Upon successful completion of the Ph.D. qualifying examination, the student becomes a computer science Ph.D. candidate. The student's Dissertation Committee must be formed within the first year of candidacy. The student selects a research advisor from within the CS Department and together they select, with the approval of the CS Graduate Committee, three additional members, at least one of whom must be from outside the WPI CS Department. The Dissertation Committee will be responsible for supervising the Comprehensive Examination and approving the dissertation proposal and final report.

The Ph.D. degree requirements consist of a course work component and a research component, which together must total at least 60 credit hours beyond the master's degree requirement. The course work component consists of at least 28 graduate credits, including 3 credits of graduate-level mathematics.

The student may also enroll for research credits, but is only allowed up to 18 research credits prior to the acceptance of the written dissertation proposal by the Dissertation Committee. With the approval of the Dissertation Committee, the student applies for and takes the Ph.D. Comprehensive Examination. This examination must be passed prior to the completion of the dissertation defense, and is normally taken after some initial dissertation research has been performed. With approval of the Dissertation Committee, the student applies for and takes the dissertation proposal examination, usually within one year of the Ph.D. candidacy.

The Ph.D. research component consists of at least 30 credits (including any research credits earned prior to the acceptance of the dissertation proposal and excluding any research credits applied toward a master's degree) leading to a dissertation and a public defense, which must be approved by the student's Dissertation Committee.

Admission Requirements

A bachelor's degree in computer science, engineering or the sciences, a technically oriented business degree or relevant experience is required for admission to the graduate program in computer science. An applicant should have proficiency in at least one recursive high-level language and some assembler language. In addition, an applicant should have a general knowledge of data structures and digital processes, and a solid foundation in mathematics.

A student may apply to the Ph.D. program upon completion of either a bachelor's (in which case the master's degree must first be completed) or master's degree in computer science or with an equivalent background.

Electrical & Computer Engineering

Programs of Study

The following general areas of specialization are available to help students structure their graduate courses: Communications and Signal Processing; Computer Engineering; Electromagnetics and Ultrasonics Engineering; Electronics and Solid State Power Engineering; Systems and Controls.

The degree of doctor of philosophy is conferred on candidates in recognition of high scientific attainments and the ability to carry on original research.

Faculty

J. A. Orr, Professor and Head; Ph.D., University of Illinois

K. A. Clements, Professor; Ph.D., Polytechnic Institute of Brooklyn

D. Cyganski, Professor; Ph.D., WPI

J. S. Demetry, Professor Emeritus; Ph.D., Naval Postgraduate School

W. H. Eggimann, Professor Emeritus; Ph.D., Case Institute of Technology

A. E. Emanuel, Professor; P.E., D.Sc., Technion-Israel Institute of Technology

H. P. D. Lanyon, Professor Emeritus; Ph.D., University of Leicester

F. J. Looft, Professor; Ph.D., University of Michigan

R. Ludwig, Professor; Ph.D., Colorado State University

K. Pahlavan, Professor; Ph.D., WPI

L. R. Ram-Mohan, Professor; Ph.D., Purdue University

E. A. Parrish, Professor and WPI President; Ph.D., University of Virginia

P. C. Pedersen, Professor; Ph.D., University of Utah

R. A. Peura, Professor of Biomedical Engineering; Ph.D.,Iowa State University

R. J. Duckworth, Associate Professor; Ph.D., University of Nottingham

H. Hakim, Associate Professor; Ph.D., Purdue University

Y. Leblebici, Associate Professor; Ph.D., University of Illinois

S. Makarov, Associate Professor; Ph.D., St. Petersburg State University, Russia

J. A. McNeill, Associate Professor; Ph.D., Boston University

W. R. Michalson, Associate Professor; Ph.D., WPI

D. Nicoletti, Associate Professor; Ph.D., Drexel University

R. F. Vaz, Associate Professor; Ph.D., WPI

M. Bromberg, Assistant Professor; Ph.D., University of California at Davis

D. Brown, Assistant Professor; Ph.D., Cornell University

C. Paar, Assistant Professor; Ph.D., University of Essen

B. Sunar, Assistant Professor; Ph.D., Oregon State University

N. Whitmal, Assistant Professor; Ph.D., Northeastern University

Research Interests

Listed are the major areas of specialization in which ECE faculty have research interests and in which courses are offered:

- Computer Engineering, including parallel and fault-tolerant processing VHDL, computer networks, and digital VLSI design.
- Communications and Signal Processing, including wireless and data communications, computer communications and image processing.

- Ultrasonics and Electromagnetics Engineering, including numerical methods and computer-aided design in electomagnetic and microwave circuits, nondestructive material evaluation and medical imaging.
- Power Systems Engineering, including power electronics and power systems.
- Electronics and Solid State, including analog IC design, solid state device theory and high-frequency circuit design.
- Systems and Controls, principally oriented to large-scale systems such as power systems.

Electrical and Computer Engineering Laboratories

Research Laboratories and Computer Facilities

The ECE Department has laboratories in the following areas: power systems, VLSI, digital communications, computer engineering, electromagnetics, global positioning, ultrasonics and nondestructive evaluation and image processing. For general computing requirements the department has many Unix workstations and Pentium- class PCs. In addition to these, students may use the College Computing Center's (CCC) facilities.

Analog Microelectronics Laboratory

The new Analog Microelectronics Laboratory was opened in 1998 under the direction of Prof. John McNeill. The National Science Foundation awarded a grant for the purchase of test and measurement equipment which will be dedicated to support work in the areas of high speed data communication, high speed imaging, and mixed signal circuit characterization. In addition to the direct impact on research, this equipment will also enable the Analog Microelectronics Laboratory to become a valuable resource for educating both undergraduates and graduate students in the complete integrated circuit design process. The lab focuses on three specific areas:

1. Analog Microelectronics for telecommunication has a goal to guide IC design by connecting system-level performance to fundamental limits imposed by circuit-level considerations, for example thermal and shot noise. Making this connection becomes more important as IC process improvements allow designers to push performance limits in speed, power, and integration.

2. High speed imaging research applies analog techniques to improve performance in high speed, wide dynamic range electronic imaging systems. Applications include machine vision and adaptive optics.

3. Mixed signal circuit characterization is concerned with developing techniques for measuring and modeling second order error sources in mixed signal circuits, for example, code-dependent noise in analog-to-digital converters.

Center for Wireless Information Networking Studies (CWINS)

This center is recognized as a pioneering facility in the important and rapidly growing area of wireless personal and data communications. The lab is supported by a broad range of networking and telecommunications corporations.

The work of CWINS is quite diverse. In recent years, basic research has been conducted in channel modeling and simulation, spread-spectrum techniques, adaptive equalization, multiple-access methods, network architectures, wireless optical communications, microstrip antennas, and RF circuit design. The lab has been particularly active in the measurement of indoor RF propagation.

Computational Fields Laboratory

The purpose of this laboratory is to serve as a computational resource to undergraduate and graduate students interested in numerical analysis as applied to problems in computational electrodynamics and acoustics. The lab contains a wide variety of platforms, including Pentium-class PCs and several workstations for X-window applications. Software utilities supporting numerical analysis (mesh-making algorithms, matrix solvers, graphics interface drivers) are of particular interest to the lab community, as is the development of integrated packages targeted for research or educational purposes.

Computer Architecture Laboratory

This laboratory contains facilities for the research and development of single-processor and multi-processor systems.

The laboratory is also equipped with logic analyzers, in-circuit emulators, and other equipment to support computer system projects. Software systems supported by this laboratory include various VLSI desegri & verification packages, several VHDL/FPGA development systems, and a variety of software development tools (C, CTT, ASW, PIC developments and so forth).

Convergent Technologies Center (CTC)

The laboratories in this center combine diverse expertise for the exploration of the emerging and converging technologies of computing, communications and cognition. The Polaroid Machine Vision Laboratory (PMVL) and Network Computing Applications and Multimedia (NETCAM) Laboratory focus on the development of new algorithms and moving emergent technologies into commercial, medical and defense related applications for its sponsors.

Research in the CTC's NETCAM lab derives from the technologies generated by the success of the internet, digital multimedia and distributed objects and middleware. Current projects explore the optimization of network protocols for multimedia, distributed object services (CORBA), and virtual reality based user interfaces.

Research in the CTC's PMVL has resulted in the development of highly efficient algorithms and new theoretical performance bounds for machine vision, automatic target recognition and image fusion for optical, IR SAR and SONAR data.

EM CAD Laboratory

The major activities in this laboratory are studies of EM wave propagation in linear and non-linear media, CAD/CAE systems for high-speed electronic/photonic devices, and RF circuits and antenna design. The lab facilities include several X-window-based workstations with access to many national laboratories and supercomputing centers.

Power Electronics and Power Systems Laboratory

This laboratory has been established for simulation of a large variety of linear, non-linear and time-varying loads, including transistor and thyristor controlled loads. It contains transducers and instrumentation for a wide range of voltages, currents and frequencies. Compatible computer equipment and A/D interfaces are available for real-time data acquisition and processing. The Power Systems Laboratory has the basic facilities for electro-mechanical energy conversion study, including sets of induction/synchronous/DC machines coupled together.

Satellite Navigation Laboratory

This laboratory provides facilities for work on civilian uses of satellite systems, especially the Global Positioning System. Receivers, signal processors and computers are provided for work on utilization of the DOD GPS system for civilian purposes, especially aircraft navigation and landing.

Ultrasonics Laboratory
Facilities in this laboratory are set up for performing basic ultrasound studies in the areas of basic acoustic research, transducer development, nondestructive testing, and medical ultrasound diagnosis. The facilities are distributed over two separate laboratory areas and contain two Testech scanning tanks for ultrasound measurements, work-stations, PCs, ultrasound pulser-receiver equipment, high-speed digitizers, frequency synthesizers, arbitrary function generator, spectrum analyzer, and various modern test equipment.

Cryptography and Information Security (CRIS) Laboratory
The CRIS Laboratory conducts research and development in cryptography and its applications. One research focus is fast implementations of the next generation of public-key algorithms such as elliptic and hyperelliptic curve schemes. We work on fast software algorithms and efficient hardware architectures. The lab is equipped with industry-standard development tools for ASIC and FPGA target hardware. We also apply Xilink FPGA's and Altera EPLD's to new types of crypto systems which allow for a fast switch of private-key encryption algorithms ("algorithm agility").

Another research focus is the integration of cryptography and data security into new communication networks. We work on the design and implementation of security protocols for wireless networks, with an emphasis on wireless LANs. Another network type of interest are high-speed Asynchronous Transfer Mode networks. We investigate system design and algorithmic issues.

The CRIS Lab is actively involved in a number of joint projects with industry. The lab has also strong ties to research groups in the U.S. and Europe with frequent exchange of graduate students. Together with strong graduate course offerings in cryptography, our research lab provides excellent opportunities for cutting-edge research and graduate education.

Networks Operations Research Laboratory
This laboratory was founded in 1997 for research in design and operational management of high-performance, efficient, and reliable computer and communication systems. Projects range from the design of low power wireless networking systems to the development of optimal algorithms for efficient digital communications, from software for securing networks to procedures for minimizing the cost of their operation. Most of this work focuses on modeling, mathematical analysis, and simulation of systems with the objective of developing innovative and cost-saving engineering and management solutions.

Current projects in the lab include: high-performance medium access sublayers, distributed wireless network power management, memory reliability, matching algorithms and implementations, service-cost tradeoffs in telecommunication networks and distributed Internet service, dynamic resource allocation with applications in portfolio optimization and digital communications, network firewalls and intrusion detection, and a computer and network performance benchmark.

Degree Requirements

For the M.S.
There are two routes to the master of science degree: the non-thesis option and the thesis option. The minimum requirement for the M.S. degree in electrical and computer engineering is 33 credits in the non-thesis program and 30 if a thesis is included. Of the minimum 33 or 30 semester hours, at least 21 must be graduate level courses (500 level) or research in the field of electrical and computer engineering taken at WPI. The remaining courses may be either at the 4000 (maximum of two) or the 500 level in computer science, physics, engineering or mathematics. The complete program must be approved by the student's advisor and the Graduate Program Committee.

Although the M.S. thesis is optional, students are encouraged to include a research component in their graduate program.

A directed research project involves a minimum of 3 credit hours of work under the supervision of a faculty member. The task is limited to a well-defined goal. Thesis research involves 9 credit hours of work, normally spread over a complete academic year. It demands more creativity on the part of the student than does a directed research project. In addition, all WPI thesis regulations must be followed.

For students completing the M.S. thesis as part of their degree requirements, a thesis committee will be set up during the first semester of thesis work. This committee will be selected by the student in consultation with his major advisor and will consist of the thesis advisor (who must be a full-time WPI ECE faculty member) and at least two other faculty members whose expertise will aid the student's research program. An oral presentation before the thesis committee and a general audience is required.

The program of study must be approved by the student's advisor, the Graduate Program Committee of the ECE Department and the WPI Committee on Graduate Studies and Research. To ensure that the program of study is acceptable, students should, in consultation with their advisor, submit it prior to the end of the semester following admission into the graduate program. Only courses that are part of an approved plan of study can be counted toward a graduate degree. Twenty-one of these credits must be WPI graduate-level electrical and computer engineering research or courses. The remaining credits may be graduate-level courses in mathematics, physics or computer science. Students must obtain prior approval from the graduate committee for the substitution of courses in other disciplines as part of their academic program.

Students may petition to transfer a maximum of 15 graduate semester credits, with a grade of B or better, after they have enrolled in the degree program. This may be made up of a combination of up to 9 credits from the WPI ECE graduate courses taken prior to formal admission and up to 9 credits from other academic institutions. No transfer credit will be given for any of WPI's undergraduate courses nor for undergraduate-level courses taken at other institutions.

All full-time students are required to attend/pass the two graduate seminar courses, EE 596A (fall semester) and EE 596B (spring semester). See course listings for details.

For the Ph.D.
Completion of 60 or more credits of graduate work beyond the master of science degree in electrical and computer engineering, including at least 30 credits of research. The same academic standards as described in the M.S. guidelines apply to the Doctor of Philosophy program. A program of study form must be completed and approved.

The doctoral student must establish two minors in fields outside of electrical engineering. Physics, mathematics and computerscience are usually recommended. Each student selects the minors in consultation with the major advisor. At least 6 credits of graduate work is required in each minor area. Courses with an ECE designation which are cross-listed in the course offerings of another department cannot be used towards fulfilling the requirements of a minor area.

Full-time residency at WPI for at least one academic year is required while working toward a Ph.D. degree. This usually corresponds to the period of active dissertation research.

Satisfactory completion of the Diagnostic Examination and the Area Examination are required.

Diagnostic Examination

The doctoral student is required to take the Diagnostic Examination during the first year in the doctoral program of study. Prior to taking this examination, a student must identify a faculty member who has indicated that he/she is willing to supervise the student's research. The purpose of the Diagnostic Exam is to determine if the student has the necessary foundation in mathematics and electrical and computer engineering to undertake doctoral studies. The Diagnostic Examination is composed of two parts; evaluation of basic know-ledge and evaluation of research skills.

Evaluation of Basic Knowledge

The examination covers fundamental concepts and selected advanced topics in electrical engineering. It is administered by the Graduate Program Committee. Students must select two areas from the following list to be examined in, in addition to the exam in the area of engineering mathematics. A description of the material covered in each examination area and sample exam questions from previous years are available from the ECE Graduate Secretary.

- Signals and Systems
- Waves and Fields
- Power Systems
- Analog Circuits and Devices
- Computers and Digital Electronics
- Engineering Mathematics

The examination on basic knowledge is a written examination and is given yearly in January. The results from the exam will be graded Pass, Conditional Pass, or Fail, by the Graduate Program Committee. Students who receive the grade of Conditional Pass must pass the exam or specified portions of the exam the following year. Students who receive the grade of Fail will not be permitted to retake the exam or any portion of the exam. No students will be permitted to take the exam or any portion of the exam more than twice.

Evaluation of Research Skills

Upon passing the examination on basic knowledge of electrical engineering, satisfactory completion of one semester of directed research under a prospective thesis advisor is required. Specific guidelines for both the Research Skills Proposal and the final Research Skills Summary Report are available from the department graduate coordinator.

Under no circumstances will a student be permitted to continue working toward the Ph.D. degree if he/she has failed either the written portion or the research portion of the Diagnostic Exam.

Area Examination

The doctoral student is required to take the Area Examination before writing a dissertation. The examination, which deals with the student's research area, is administered by a committee consisting of the student's major advisor and other experts in the area of the student's research. Students who fail the examination may retake it at a later date with the approval of the ECE Graduate Program Committee. Upon passing both the Area and Diagnostic examinations, a student should make formal application for admission to candidacy. This application must be approved by the ECE Department and the Committee on Graduate Studies and Research at least eight months before the doctorate is to be granted.

Dissertation

All students must complete and orally defend a dissertation prepared under the general supervision of the major advisor who must be a full-time faculty member of the ECE Department. The research described in the dissertation must be original and constitute a contribution to knowledge in the major field of the candidate. The Dissertation Committee normally serves as the Defense Committee as well and certifies the quality and originality of the dissertation research, the satisfactory execution of the dis-sertation, and the preparedness of the defense. The Dissertation Committee consists of the major advisor (as committee chairperson) and at least two additional faculty members whose expertise will aid the student's research program. At least two members of the committee must be full-time WPI ECE Faculty and at least one member must be from outside the student's department. This committee will be selected by the student in consultation with his major advisor.

For the Combined B.S./M.S. Program

A student accepted into the B.S./M.S. Program may use 6 credit hours of work for both the B.S. and M.S. degrees. Additional graduate credit hours of work (beyond the 15 units required for the B.S. degree) up to a total of 12 credit hours may be transferred from the student's undergraduate transcript. All of these course credits must be defined prior to enrollment in the courses.

A student must define the 12 credit hours at the time of applying to the B.S./M.S. Program. The 12 credit hours may be all advanced undergraduate courses, graduate courses, or combinations of both at the discretion of the student's advisor subject to the approval of the ECE Department Graduate Program Committee.

At the start of Term A in the senior year, but no later than at the time of application, students are required to submit to the graduate coordinator of the Electrical and Computer Engineering Department a list of proposed courses to be taken as part of the master's degree program. A copy of the student's transcript (grade report) must be included with the application.

Admission Requirements

Holders of bachelor's or master's degrees in electrical engineering or a related field are invited to submit an application for admission. Students with the bachelor of technology or the bachelor of engineering technology degree must complete about 1 1/2 years of undergraduate study in electrical engineering before they can be admitted to the graduate program.

Applicants without a B.S. degree in electrical engineering, but who hold a B.S. degree in mathematics, computer engineering, physics or another engineering discipline may apply for admission to the M.S. degree program in electrical and computer engineering with the following requirements:

Basic skills: Students must have passed EE 2201, EE 2311, EE 3801 and EE 3111, or equivalent, with grades of B or better. Please consult the WPI Undergraduate Catalog for course descriptions.

Specialized skills: Students must pass a minimum of two of the following courses (or equivalent) with grades of B or better before the end of the second semester of the M.S. program: EE 4203, EE 4304, EE 4502, EE 4801, EE 4902, ES 4012. Students must complete 24 additional graduate credits at WPI for the M.S. degree (27 in the non-thesis option).

Students with a master of science degree in electrical and computer engineering may apply for the doctoral program of study. Admission to the Ph.D. program will be based on a review of the application and associated references.

Fire Protection Engineering

Programs of Study

Fire protection engineers specialize in applying modern technology to the solution of firesafety problems. The successful fire protection engineer must know something about building construction and industrial processes; must interact with and be somewhat competent in other design professions including architecture and electrical, mechanical, civil and chemical engineering. In addition, the firesafety aspects of human behavior, business, management and public administration are important aspects of practice.

The fire protection engineering program at WPI adapts previous educational and employment experiences into a cohesive plan of study. Consequently, the program is designed to be flexible enough to meet specific and varying student educational objectives. Students can select combinations of major courses, non-major courses, thesis and project topics that will prepare them to proceed in the career directions they desire. The curriculum can be tailored to enhance knowledge and skill in the general practice of fire protection engineering, in fire protection engineering specialties (such as industrial, chemical, energy, power), or in the more theoretical and research-oriented sphere.

Practicing engineers or others already employed and wishing to advance their technical skills may enter the evening program as part-time students or take off-campus courses via WPI's Advanced Distance Learning Network (see page 90) The master's degree may be completed on a part-time basis in three to five years, depending on the number of courses taken each semester.

WPI offers both master's and doctoral degrees as well as the Advanced Certificate and Graduate Certificate in Fire Protection Engineering.

Faculty

D. A. Lucht, Professor of Fire Protection Engineering and Director; B.S., Illinois Institute of Technology

R. W. Fitzgerald, Professor of Fire Protection Engineering and Civil Environmental Engineering; Ph.D., University of Connecticut

B. J. Savilonis, Professor of Mechanical Engineering; Ph.D., State University of New York

R. G. Zalosh, Professor of Fire Protection Engineering; Ph.D., Northeastern University

J. R. Barnett, Associate Professor of Fire Protection Engineering; Ph.D., WPI

F. Noonan, Associate Professor of Fire Protection Engineering and Management; Ph.D., University of Massachusetts

N. A. Dembsey, Assistant Professor of Fire Protection Engineering; Ph.D., University of California at Berkeley

E. V. Clougherty, Adjunct Professor

R. P. Schifiliti, Adjunct Associate Professor

Research Interests

Faculty research interests cover a wide range of topics in fire protection engineering and related areas. Research is directed toward both theoretical understandings and the development of practical engineering methods.

Specific capabilities and interests include computer modeling, fire performance of structural systems, fire growth and smoke characterization, fire and smoke dynamics, firesafety design methods for buildings, ships, and submarine applications, explosion phenomena, failure analysis, risk assessment, process safety management and risk management concepts.

Fire Science Laboratory

This new and expanded laboratory facility supports experimentation in fire dynamics, combustion/explosion phenomena, detection, fire and explosion suppression. The cone calorimeter, standard flame spread apparatus, infrared imaging system, phase doppler particle analyser, and room calorimeter are also available with associated gas analysis and data acquisition systems.

The new wet lab area will support water-based fire suppression and demonstration projects.

Serving as both a teaching and research facility, the lab accommodates undergraduate projects as well as graduate students in fire protection engineering, mechanical engineering and related disciplines.

Combined B.S./M.S. Program

High school seniors can apply for this five-year program. This gives high school graduates the opportunity to complete the undergraduate degree in a selected field of engineering and the master's degree in fire protection engineering in five years. Holders of B.S. degrees in the traditional engineering fields and the master's degree in fire protection engineering enjoy extremely good versatility in the job market.

Graduate Internships

A unique internship program is available to fire protection engineering students, allowing them to gain important clinical experiences in practical engineering and research environments. Students are able to earn income by alternating work and on-campus classroom and laboratory activities. With departmental permission, students may take courses during the full-time work cycle.

Degree Requirements

For the M.S.

The M.S. fire protection engineering program is flexible and can be tailored to individual student career goals. The fire protection engineering master's degree requires 30 semester hours of credit including the Thesis (FPE 590) or Graduate Project (FPE 592). A courses-only option is also available with a minimum of 30 semester hours of credit.

For the Ph.D.

Ph.D. students must complete a minimum of 90 semester hours of graduate work after the bachelor's degree (or 60 semester hours after the master's). This includes at least 15 semester hours of fire protection engineering course credits and 30 hours of dissertation research.

Doctoral students must successfully complete the Fire Protection Engineering Qualifying Examination (FPEQE), a research proposal and public seminar and the dissertation defense.

Admission Requirements

High school graduates applying for the Combined B.S./M.S. Program must meet normal undergraduate admission criteria and submit a two page essay articulating their interest in the field. Applicants for the master's or certificate programs should have a B.S. in engineering, engineering technology or the physical sciences. Applicants with no FPE work experience should submit a two page essay articulating their interest in the field.

Students with science degrees and graduates of some engineering disciplines may be required to take selected undergraduate courses to round out their backgrounds.

Applicants for the doctor of philosophy in fire protection engineering should have strong academic backgrounds in any of a host of engineering or science disciplines.

For more information, contact the Center for Firesafety Studies, 508-831-5593, via e-mail at fpe@wpi.edu., or on the web at http//:www.wpi.edu/+FPE.

Management

Programs of Study

Better. Faster. Smarter. That is what today's executives want from tomorrow's executives, but those attributes are increasingly difficult to achieve in today's fast paced business environment. Increasingly, people are turning to the Master of Business Administration (M.B.A.) to equip themselves to work better, work faster, and work smarter so they can be tomorrow's leaders. At WPI, we have been helping people develop those attributes since 1974.

At WPI, our education is focused on what you need to succeed. Our highly integrated, applications-oriented M.B.A. program provides our students with the "big picture" perspective required of successful upper-level managers, and the hands-on knowledge needed to meet the daily demands of the workplace. Our focus on the management of technology comes from our recognition that rapidly changing technology is driving the pace of business; we make sure our students understand leading technology-based organizations, integrating technology into organizations, and creating new processes, products, and organizations based on technology. Our strong emphasis on behavior skills prepares you to be a leader in any organization, and the global threads throughout our curriculum ensure that you will understand the global imperative facing all businesses.

WPI's M.B.A. program features a 16-credit core of five cross-functional courses designed to give students a larger framework for understanding disciplinary material that is critical for managers in a globally-competitive, technological world. Core courses include: Interpersonal and Leadership Skills for Technological Managers; Creating and Implementing Strategy for Technological Organizations; Creating Processes in Technological Organizations; Business Analysis for Technological Managers; and Legal and Ethical Context of Technological Organizations.

Leadership, ethics, communication and a global perspective are emphasized throughout the core, all within our focus on the management of technology.

Each core course, with the exception of Legal and Ethical Context of Technological Organizations, has pre-requisite requirements from within our 18-credit Foundation. The purpose of the foundation is to ensure that students have a solid understanding of the basic functions carried out in organizations and of the environment in which they operate, as well as an introduction to the tools used to analyze business problems. Foundation courses consist of the following nine 2-credit courses, each of which covers a major functional area of business: **Financial Accounting; Finance; Organizational Behavior; Production/Operations Management; Quantitative Methods; Principles of Marketing; Management Information Systems; Economics of the Firm; and Domestic & Global Economic Environment of Business.** Foundation-level courses are potentially waivable based on prior graduate or undergraduate coursework.

The M.B.A. program also features a capstone Graduate Qualifying Project (GQP) which provides students with a hands-on real world opportunity to apply and enhance their classroom experience.

M.B.A. students are required to complete 12 credit hours of free elective coursework, which may be taken within the Management Department or within other academic departments at WPI. In addition, students may select a 6-credit Option for Specialization, which requires 6 additional credits in a particular functional area, in combination with at least 6 credits of the free electives in the chosen area.

The M.S. in Marketing and Technological Innovation is a highly specialized 30-credit hour degree program and is specifically designed for individuals employed in or aspiring to work in marketing positions and/or positions responsible for innovation within technology-oriented environments. The M.S. in Marketing and Technological Innovation features 15 credit hours of required coursework including: MG 503 Organizational Behavior; MG 505 Quantitative Methods; MG 506 Principles of Marketing; MG 508 Economics of the Firm; MG 511 Interpersonal and Leadership Skills for Technological Managers; and MG 512 Creating and Implementing Strategy for Technological Organizations.

Students then select 15 credit hours of electives from the following list of courses: MG 531 Managing Organizational Change; MG 546 Managing Technological Innovation; MG 547 Project Management; MG 548 Productivity Management; MG 561 Marketing Research; MG 562 Technology Transfer and New Product Development; MG 563 Marketing of Emerging Technologies; MG 564 Global Technology Marketing; MG 566 Marketing and Electronic Commerce; MG 572 Telecommunications Management and Electronic Commerce; MG 592 New Venture Management and Entrepreneurship; MG 597 Internship; MG 598 Independent Study.

Students who have completed prior undergraduate or graduate-level coursework which satisfies the content of a foundation-level requirement (MG 503, MG 505, MG 506, MG 508) may request a waiver of the relevant foundation course. Students granted waivers must then take an additional 2 credit hours of elective coursework for each foundation course waived, either in the area of the waiver or in the "major" area.

WPI's M.S. in Operations and Information Technology is a highly specialized 30 credit hour degree program and is specifically designed for individuals employed in or aspiring to work in production/operations positions or management information systems (MIS) positions. The M.S. in Operations and Information Technology features 12 credit hours of required coursework including:
MG 503 Organizational Behavior;
MG 504 Production/Operations Management;
MG 507 Management Information Systems; MG 511 Interpersonal and Leadership Skills for Technological Managers; and MG 513 Creating Processes in Technological Organizations.

Students then select 18 credit hours of electives from the following list of courses: MG 505 Quantitative Methods; MG 531 Managing Organizational Change; MG 542 Quality Planning and Control; MG 544 Supply Chain Management and Electronic Commerce; MG 545 Production Systems Design; MG 546 Managing Technological Innovation; MG 547 Project Management; MG 548 Productivity Management; MG 549 Strategies for Manufacturing Firms; MG 566 Marketing and Electronic Commerce; MG 571 Database Applications Development; MG 572 Telecommunications Management and Electronic Commerce; MG 573 Systems Design and Development; MG 575 Information and Decision Support Systems; MG 592 New Venture Management and Entrepreneurship; MG 597 Internship; MG 598 Data Mining; MG 598 Independent Study.

Students who have completed prior undergraduate or graduate-level coursework which satisfies the content of a foundation-level requirement (MG 503, MG 504, MG 507) may request a waiver of the relevant foundation course. Students granted waivers must then take an additional 2 credit hours of elective coursework for each foundation course waived, either in the area of the waiver or in the "major" area.

A Combined B.S./M.B.A. program is available to WPI undergraduate students. A separate and complete application to the M.B.A. program must be submitted. Admission to the Combined Program is determined by the faculty of the Management Department . 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 M.B.A. 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./M.B.A. must complete the following courses while an undergraduate: MG 1100 Financial Accounting; MG/IE 2200 Financial Management; MG/IE 2300 Organizational Science; MG/IE 3400 Production System Design; MA 2611 Applied Statistics I; MA 2612 Applied Statistics II; MG 3600 Marketing Management; MG 3700 Information Systems Management; SS 1110 Introductory Microeconomics; SS1120 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 M.B.A. via the Combined Program, the student must satisfy all M.B.A. 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.

Please refer to the section on the Combined Programs (page 98) or contact the director of graduate management programs for more information.

Department Research

In addition to teaching, Management Department faculty are involved in a variety of sponsored research and consulting work. A sampling of current research includes: quality control in information-handling processes; supply chain management; management of biotechnology; decision/ risk analysis; conflict management; Latin American economic development; capacity planning; international accounting differences; strategy and new venture teams; and re-engineering business education.

The **Collaborative for Entrepreneurship and Innovation,** a program within the Department of Management, inspires and nurtures people to discover, create, and commercialize new products, services, and organizations based on technology. It coordinates all entrepreneurial activities at WPI, including graduate and undergraduate courses, business plan competitions, a student organization, and the Massachusetts Collegiate Entrepreneur Award competition. Additional programs and activities are planned, including various awards, a social entrepreneurship program, and entrepreneurship internship program, and various youth and K-12 programs for teachers and students. An affiliated program, the WPI Venture Forum, offers monthly educational programs, networking opportunities, and a newsletter. For more information about the Collaborative for Entrepreneurship and Innovation or other entrepreneurial activities at WPI, please call (508) 831-5075 or 5218.

Faculty

M. C. Banks, Harry G. Stoddard Professor of Management and Head; Ph.D., Virginia Tech

A. Gerstenfeld, Professor; Ph.D., Massachusetts Institute of Technology

J. T. O'Connor, Professor; Ph.D., Notre Dame University

H. G. Vassallo, Professor; Ph.D., Clark University

M. B. Elmes, Associate Professor; Ph.D., Syracuse University

L. S. Graubard, Associate Professor; A.B.D, Brown University

S. A. Johnson, Associate Professor; Ph.D., Cornell University

C. Kasouf, Associate Professor; Ph.D., Syracuse University

F. Noonan, Associate Professor; Ph.D., University of Massachusetts

D. Strong, Associate Professor; Ph.D., Carnegie-Mellon University

E. Danneels, Assistant Professor; Ph.D., Pennsylvania State University

H. Higgins, Assistant Professor; Ph.D., Georgia State University

E. T. Loiacono, Assistant Professor; Ph.D., University of Georgia

J. J. Mistry, Assistant Professor; D.B.A., Boston University

O. Volkoff, Assistant Professor; Ph.D., University of Western Ontario

K. A. Wilkens, Assistant Professor; Ph.D., University of Massachusetts

A Zeng, Assistant Professor; Ph.D., Pennsylvania State University

J. Zhu, Assistant Professor; Ph.D., University of Massachusetts

Degree requirements

For the M.B.A.

9 credits, prior to waivers, distributed as follows (credit in parenthesis):

- **9 Foundation courses** (or graduate/ undergraduate equivalents):
  MG 501, MG 502, MG 503, MG 504, MG 505, MG 506, MG 507, MG 508,
  MG 509 (2 credits each)
- **5 Core Courses:**
  MG 511 (3 credits), MG 512 (4 credits),
  MG 513 (3 credits), MG 514 (4 credits),
  MG 515 (2 credits)
- **Graduate Qualifying Project (GQP):**
  MG 516 (3 credits)
- **Elective Courses:**
  12 credits

For the M.S. in Marketing and Technological Innovation

30 credits, distributed as follows (credit in parenthesis):

- **4 Foundation Courses** (or graduate/ undergraduate equivalents):
  MG 503, MG 505, MG 506, MG 508
  (2 credits each)
- **2 Core Courses:**
  MG 511 (3 credits), MG 512 (4 credits)
- **5 Elective Courses, selected from the following:**
  MG 531, MG 546, MG 547, MG 548, MG 561, MG 562, MG 563, MG 564, MG 566, MG 572, MG 592, MG 597, MG 598 (3 credits each)

For the M.S. in Operations and Information Technology

30 credits, distributed as follows (credit in parenthesis):

- **3 Foundation Courses** (or graduate/ undergraduate equivalents):
  MG 503, MG 504, MG 507 (2 credits each)
- **2 Core Courses:**
  MG 511, MG 513 (3 credits each)
- **6 Elective Courses,** selected from the following:
  MG 505 (2 credits),
  MG 531, MG 542, MG 544, MG 545, MG 546, MG 547,MG 548, MG 549, MG 566, MG 571, MG 572, MG 573,MG 575, MG 592, MG 597, MG 598 (3 credits each)

All students admitted to a graduate management degree program are assigned a faculty advisor and must file a curriculum plan during their first year in the program.

Part-time students typically complete the M.B.A. program in three to five years, dependent on prior academic background, while full-time students may complete the program in as little as one year, dependent on prior academic background. An M.S. degree program is typically completed in two to four years part-time, or one year full-time.

Admission Requirements

Admission to WPI's Graduate Management Programs is competitive. Admission is granted to applicants whose academic and professional records indicate the likelihood of success in a challenging academic program, and whose career aspirations are in line with the focus of the specific degree program to which they are applying.

Applicants should have the analytic aptitude and academic preparation necessary to complete a technology-oriented management program. This includes a minimum of three semesters of college-level math or two semesters of college-level calculus. Applicants are also required to have an understanding of computer systems.

Applicants must have the earned equivalent of a four-year U.S. bachelor's degree to be considered for admission. Admission decisions are based upon all the information required from the applicant.

Locations

Tailored to meet the challenges of working professionals, WPI offers full- and part-time graduate management study at our campuses in Worcester and Waltham (MA) as well as world-wide via our Advanced Distance Learning Network (see page 21).

Manufacturing Engineering

Programs of Study

Manufacturing Engineering offers three graduate degrees: the master of engineering, the master of science and the doctor of philosophy.

The master of engineering, non thesis, degree is intended to appeal to students who are in every way qualified for graduate studies, but have no professional need to carry out an independent research project on the scale of a master's thesis. The basic philosophy of this degree is also to build a solid and broad foundation in the modern manufacturing practice.

The master's program in manufacturing engineering provides opportunities for students to study modern manufacturing techniques while gaining a solid science base in this multidisciplinary field. Course material and research activities draw heavily from traditional fields of computer science, controls engineering, electrical and computer engineering, environmental engineering, industrial engineering, materials science and engineering, mechanical engineering, manufacturing engineering and management. The program is intended to build a solid and broad foundation in modern manufacturing practices, and allow further concentrated study in a selected specialty.

The program is intended to educate engineering professionals who are strongly committed to a career in manufacturing and wish to understand and practice modern manufacturing engineering.

A Ph.D. program is also available in manufacturing engineering. It is the goal of this program to train people for careers in research and teaching of manufacturing engineering and materials processing. Students interested in the Ph.D. program in manufacturing engineering should contact the director of manufacturing engineering for details.

Research Interests

Current research areas include intelligent processing of materials, nondestructive testing, intelligent design, intelligent control engineering, automation engineering, application of robotics, surface engineering, topographic analysis for concurrent engineering, traditional and nontraditional machining, grinding, manufacturing management engineering, computer integration and control of manufacturing operations, processing of polymers and composite materials, design for manufacturability, pollution prevention engineering and design for the environment, fixture and tooling, computer-aided design and manufacturing (CAD/CAM).

Faculty

S. Mirza, Professor of Practice, Interim Director of Manufacturing Engineering; Ph.D., University of Wisconsin, Madison.

D. Apelian, Howmet Professor of Engineering, Executive Director of the Metal Processing Institute; Ph.D., Massachusetts Institute of Technology

R. R. Biederman, George F. Fuller Professor of Mechanical Engineering; Ph.D., University of Connecticut

D. C. Brown, Professor of Computer Science; Ph.D., Ohio State University

R. N. Katz, Norton Research Professor; Ph.D., Massachusetts Institute of Technology

R. Ludwig, Professor of Electrical and Computer Engineering; Ph.D., Colorado State University

J. C. O'Shaughnessy, Professor of Civil and Environmental Engineering; Ph.D., Penn State University

R. D. Sisson Jr., Professor of Mechanical Engineering, Ph.D., Purdue University

H. K. Ault, Associate Professor of Mechanical Engineering; Ph.D., WPI

C. A. Brown, Associate Professor of Mechancal Engineering and Director of Manufacturing Engineering; Ph.D., University of Vermont

S. A. Johnson, Associate Professor of Management; Ph.D., Cornell University

M. M. Makhlouf, Associate Professor of Mechanical Engineering, Director of Aluminum Casting Research Laboratory; Ph.D., WPI

D. W. Nicoletti, Associate Professor of Electrical and Computer Engineering; Ph.D., Drexel University

F. Noonan, Associate Professor of Management; Ph.D., University of Massachusetts

Y. Rong, Associate Professor of Mechanical Engineering; Ph.D., University of Kentucky

J. M. Sullivan Jr., Associate Professor of Mechanical Engineering; Ph.D., Thayer School of Engineering, Dartmouth College

M. A. Demetriou, Assistant Professor of Mechanical Engineering; Ph.D., University of Southern California

M. S. Fofana, Assistant Professor of Mechanical Engineering; Ph.D., University of Waterloo

P. D. Cotnoir, Visiting Lecturer in Mechanical Engineering and Director of Central Massachusetts Manufacturing Partnership; M.S., WPI

Research Facilities and Laboratories

The program has access to extensive research facilities through Robotics and the Computer Integrated Manufacturing (CIM) laboratories as well as the Metals Processing Institute. These labs combine a large machinery bay area with an attached air conditioned computer laboratory with viewing access into the machinery area. Equipment in the Robotics Lab includes a number of industrial robots set up for deburring, welding, assembly, and metrology, a Coordinate Measurement Machine (CMM) with data acquisition and GD&T software, a machining area with CNC machine tools, and a range of specialized automation equipment interfaced to PLC's and PC's for various engineering applications (such as topographic analysis and force dynamometry). The CAM Lab includes several Unix-based engineering graphics workstations used for CAD, solid modeling, kinematic analysis, FEA, CIM and expert system development, and a number of 486/Pentium computers set up for data acquisition and real-time control. The Design Studio will combine Rapid Prototyping technology and audio-visual communication to enable multi-university engineering projects composed of virtual design teams. The manufacturing program has access to other campus facilities such as the College Computer Center and labs in the Computer Science and Electrical and Computer Engineering Departments, through an ethernet LAN. Cooperative research is frequently done with faculty in many areas.

Metal Processing Institute (MPI)

See complete description on page 51.

Degree Requirements

For the M.S.

The master of science requires 24 credit hours of course work, and 6 credit hours of thesis research. The course work is broken down into 12 credit hours of required core courses, 9 credit hours of specialized studies in one area of focus, and a 3-credit-hour elective course. All full-time students are required to participate in ongoing seminar series and take four 3-credit core courses, preferably during their first year: MFE 500, MFE 510, MFE 520, MFE 530, and MFE 540. The seminar series provides a common forum for all students to discuss advanced techniques dealing with operations in manufacturing, materials processing, and control and monitoring of manufacturing processes. The four required core courses focus on particularly broad thrusts in manufacturing science and technology, which cannot be gained through any single traditional discipline.

The student is required to develop strength in one area directly supporting advanced manufacturing through a carefully selected three or four course sequence. Currently identified areas include artificial intelligence, environmental engineering/pollution prevention, information systems and networks, intelligent materials processing systems, materials processing and engineering, digital image processing, computational mechanics, design of mechanical assemblages, manufacturing systems engineering, and industrial engineering.

Students will culminate their studies with a master's thesis. The thesis will be developed to augment one of the ongoing research projects and/or advanced areas of study in the program. A graduate examination committee consisting of a thesis advisor and two additional faculty members will review and monitor the thesis project. In cases where appropriate, one of these two additional members may be selected from outside the MFE program faculty. Students will be encouraged to publish results of thesis studies in the open literature.

For the M. Eng.

The master of engineering (M. Eng.) requires at least 30 graduate level credits, which include at least 12 credits within Manufacturing Engineering (preferable MFE 510, MFE 520, MFE 530, and MFE 540), at least 9 credits in specialized studies, 3-6 credits of directed research MFE 598, and 3-6 credits of elective courses. The directed research may take the form of a project proposed by the student, completed under the guidance of a faculty member, and, if possible, done in collaboration, with an industrial contact. Students are encouraged but not required to select an area within manufacturing engineering on which to focus at least nine of their course and directed research credits. Registration for, attendance at, and participation in ongoing seminar series is required for full-time students with counsel of the advisor. The M. Eng. degree does not require a thesis.

Changing to Master's Programs

Any student in the M.S. program may request a switch into the M. Eng. program by submitting his/her request in writing to the MFEGC. Before acting on such a request, the MFEGC will require and seriously consider written input from the student's thesis advisor. Departmental financial aid given to the M.S. students who are permitted to switch to the M. Eng. program will automatically be withdrawn. Subject to the approval of the MFEGC, a maximum of 3 credits of thesis research (MFE 599) earned by a student in the M.S. program may be transferred to directed research credit (MFE 598) in the M. Eng. program.

Students in the M. Eng. program may switch into the M.S. program at any time by notifying the MFEGC of the change, provided that they have identified a thesis advisor, formed a thesis committee, and have worked out a plan of study with their thesis advisor. In the case of such a transfer, all credits (including directed research) earned in the M. Eng. program automatically will be transferred to the M.S. program. Subjected to the thesis advisor's approval, directed research credits (MFE 598) earned in the M. Eng. program may be transferred to thesis research credits (MFE 599) in the M.S. program.

The guidelines for switching from the M.S. program to the M. Eng. program apply to all M.S. students, including those admitted prior to the fall of 1999

For the Ph.D.

It is highly recommended that students who plan on conducting their M.S. or Ph.D. research in quality control courses or manufacturing systems simulation take the following mathematical science classes early in their program: MA 542, MA 544, and MA 546. These courses will strengthen the students' ability to analyze the experimental data and guide improvements and design efforts. For the admission to Ph. D., a master's degree in science or engineering is required.

Admission Requirements

Candidates for admission should have a bachelor's degree in science or engineering related to manufacturing, preferably in such fields as computer science/engineering, electrical/control engineering, industrial engineering, environmental engineering, manufacturing engineering, materials science and engineering, or mechanical engineering. Candidates should also possess a strong mathematical background. Students with other backgrounds will be considered based on their interest in the field, formal education, and professional experience in manufacturing.

Materials Science & Engineering

Leading to the degree of master of science and doctor or philosophy. Full- and part-time study available.

For more information, contact the program head at 508-831-5633.

Program of Study

The master of science in materials science and engineering provides students with an opportunity to study the fundamentals of materials science and state-of-the-art applications in materials engineering and materials processing. The program is designed to build a strong foundation in materials science along with industrial applications in engineering, technology, and processing.

Program areas for the doctor of philosophy emphasize physical metallurgy and ceramics, electron microscopy, mechanical behavior of materials, fracture mechanics, reliability analysis, corrosion, tribology, and X-ray diffraction analysis, polymer processing and properties, biomaterials, as well as more general programs involving materials processing, materials science and life cycle analysis.

Well-equipped laboratories within Washburn Shops and Stoddard Laboratories include such facilities as scanning (SEM) and transmission (TEM) electron microscopes, X-ray diffractometer, process simulation equipment, a mechanical testing laboratory including two computer controlled servo-hydraulic mechanical testing systems, metalcasting, particulate processing, semi-solid processing laboratories, a tribology laboratory, a metallographic laboratory, a polymer engineering laboratory with differential scanning calorimeter (DSC) and thermo gravimetric analyzer (TGA), a corrosion laboratory, topographic analysis laboratory and machining force dynamometry. A range of materials processing, fastening, joining, welding, machining, casting and heat treating facilities is also available.

Faculty

R. D. Sisson Jr., Professor of Mechanical Engineering, Materials Science and Engineering Program Head; Ph.D., Purdue University

D. Apelian, Howmet Professor of Engineering, Director of the Metal Processing Institute; Sc.D., Massachusetts Institute of Technology

I. Bar-On, Associate Professor; Ph.D., Hebrew University of Jerusalem

R. R. Biederman, George F. Fuller Professor of Mechanical Engineering; Ph.D., University of Connecticut

R. F. Bourgault, Professor Emeritus; M.S., Stevens Institute of Technology

C. A. Brown, Associate Professor; Director of Manufacturing Engineering; Ph.D., University of Vermont

C. D. Demetry, Associate Professor; Ph.D., Massachusetts Institute of Technology

R. N. Katz, Norton Research Professor, Ph.D., Massachusetts Institute of Technology

M. M. Makhlouf, Associate Professor, Director of the Aluminum Casting Research Laboratory; Ph.D., WPI

S. Shivkumar, Associate Professor; Ph.D., Stevens Institute of Technology

K. Zeisler-Mashl, Research Assistant Professor; Ph.D., Michigan Technological University

Materials Science and Engineering Laboratories

Biomaterials Laboratory

This laboratory contains facilities for the synthesis, processing and testing of biomaterials. The equipment include foam processing apparatus, data acquisition systems, medical devices, sensors, polymer and synthesis modules, constant temperature shaker baths, centrifuges, Shore hardness testers, ASTM ball rebound testers and other polymer testing equipment.

Ceramic/Powder Processing Laboratory

This industry-sponsored laboratory supports particulate processing research by Materials Science and Manufacturing students and faculty. The laboratory is equipped with a variety of powder preparation, processing and characterization equipment, as well as equipment for green body consolidation and sintering. Equipment includes roller mills, mixers, a low temperature drying oven, freeze dryer, cold press, various sintering furnaces (capable of up to 1700C in air and controlled atmospheres), a differential thermal analyzer, x-ray sedigraph, and equipment for electrical property and density measurements.

Electrochemistry, Tribology and Corrosion Laboratories

These experimental facililties are for the study of corrosion, erosion, wear and electrochemisty of materials. Included are potentiostat/galvanostats for experimental control and data collection using and EG&G Princeton Applied Research Company computer-assisted electrochemistry system. Also available is equipment for fretting corrosion, cavitation erosion and dry sliding friction testing.

Mechanical Testing Laboratory

The purpose of the Mechanical Testing Laboratory is to characterize materials in support of reliability and life predictions, materials development, and materials performance evaluations. The laboratory is involved in test and standards development and regularly participates in national and international "round robin" test programs. Some current projects include: the study of fracture toughness and fatigue crack propagation of ceramics, testing of shape memory alloys, concrete and metal matrix composites.

The equipment includes two 250 kN computer-controlled Instron servo-hydraulic test systems with supporting environmental chambers for high-temperature and low-temperature testing of metals, ceramics and composites, and ASEA triaxial-loading tensile tester, a 1000 N screw-driven tensile tester, stress-rupture furnaces, and supporting attachments.

Metal Processing Institute (MPI)

http://www.WPI.EDU/Academics/Research/MPI

The Metal Processing Institute (MPI) is an industry-university alliance. Its mission is to design and carry out research projects identified in collaboration with MPI's industrial partners in the field of near and net shape manufacturing. MPI creates knowledge that will help enhance the productivity and competitiveness of the metal processing industry, and develops the industry's human resource base through the education of WPI students and the dissemination of new knowledge. More than 120 private manufacturers participate in the institute and their support helps fund fundamental and applied research that addresses technological barriers facing the industry. The MPI researchers also develop and demonstrate best practices and state-of-the-art processing techniques.

MPI offers educational opportunities and corporate resources to both undergraduate and graduate students.

Specifically:

- International exchanges and internships with serveral leading universities around the globe — Europe and Asia.
- Graduate internship programs leading to Masters or Doctoral degree where the research work is carried out at the industrial site.

For further details visit the MPI office on the third floor of Washburn, Room 326 or the MPI website: *www.WPI.EDU/Academics/Research/MPI*.

MPI's research programs are carried out by four distinct research consortia. These are described below:

- Aluminum Casting Research Laboratories (ACRL)
- Center for Heat Treating Excellence (CHTE)
- Powder Metallurgy Research Center (PMRC)
- Semisolid Materials Processing Center (SSMC)

Aluminum Casting Research Laboratory (ACRL)

http://www.WPI.EDU/Academics/Research/ACRL

The laboratory provides experimental facilities for course laboratories and for undergraduate and graduate projects. The laboratory is equipped with extensive melting and casting facilities, computerized data acquisition systems for solidification studies, thermal analysis units, liquid metal filtration apparatus, rheocasting machines and a variety of heat treating furnaces. The laboratory has strong collaborations with industry and students work directly with professional engineers from sponsoring companies. Thirty-five (35) corporate members participate in and support the ACRL research programs. Student scholarships offered by the Foundry Education Foundation (FEF) are available through the laboratory. The ACRL conducts workshops, seminars, and technical symposiums for national and local industries. The laboratory is available throughout the year for project activity and thesis work as well as co-op and summer employment. Project opportunities at international sites are also available through ACRL/MPI.

Center for Heat Treating Excellence (CHTE)

http://www.WPI.EDU/Academics/Research/CHTE

The center was established in 1999 to address the scientific and engineering issues facing the heat treating industry, which is comprised of over 500 corporations in North America alone. ASM's Heat Treating Society (HTS) and the Metal Treating Institute (MTI) are founding members of the CHTE, along with a distinguished group of leading corporations. With the help of the Department of Energy's Office of Industrial Technologies, a document "Vision 2020 and Roadmap" for the heat treating industry has been developed. CHTE's agenda is to address the fundamental and long-term research needs of the heat treating industry.

Powder Metallurgy Research Center (PMRC)

http://www.WPI.EDU/Academics/Research/PMRC

The center addresses the scientific, engineering, and managerial problems of the powder metallurgy industry. By integrating facilities from different disciplines, the center has developed research programs in engineering and management, addressing new technologies as well as methodologies for their implementation, i.e., valve creation and management issues in a small fragmented industry. The objectives of the PMRC are as follows:

- Establish an educational and research center for the Powder Metallurgy Industry, and to provide a vehicle for manufacturing excellence and competitiveness of the industry.
- Establish long term relationships between the academic community and members of management, manufacturing, and research in the P/M industry.
- Develop course and project experiences for graduate and undergraduate students that will foster an understanding of the industry.

Nineteen corporate members participate and support the PMRC research programs. MQP project opportunities, industrial internships, co-op opportunities and summer employment are available through PMRC/MPI.

Semisolid Materials Processing Laboratory (SSMP)
http://www.WPI.EDU/Academics/Research/SSMC
Semisolid Materials Processing Laboratory brings together, in a multidisciplinary and participatory fashion, the academic and industrial communities interested in semisolid technologies. The goal of the laboratory is to produce a concentrated effort directed toward achieving a better understanding of fundamental issues concerning semisolids, such as their constitutive behavior and their performance during processing.

The laboratory facilities include metal casting facilities, workstations for modeling work, complete metallurgical analysis and characterization facilities.

1. The laboratory has joint research programs with the solidfication laboratory at MIT and Oak Ridge National Laboratory. The laboratory has also exchange programs with the University of Aachen in Germany, and the Norwegian University of Science and Technology where students can perform projects.

2. SSMC research agenda focuses on flow behavior as a function of process parameters such as temperature, solid fraction, microstructure and process history; and simulation of shape-making operations and correlation with experiments. Seventeen (17) corporate members participate in support the SSMC research agenda.

NMR Spectroscopy Laboratory
This laboratory houses a Brucker 200 MHz 48 Transfourier nuclear magnetic resonance spectroscopy system for proton and C13 as well as from silver to phosphorus magnetic resonance analysis.

Optical and Electron Metallography Laboratories
Two scanning electron microscopes (SEMS), an analytical scanning transmission electron microscope (AEM), optical reflection and transmission microscopes, and supporting sample preparation and photographic equipment are the major facilities available for microstructural analysis. The AMR1200 (SEM) is equipped with a Kevex 7000 Energy Dispersive X-Ray (EDX) Analyzer. The JSM840 (SEM) is equipped with stage automated digital image analysis, a light element (Uranium down to Boron) Quantum X-Ray detector with a Kevex Delta system, and a wavelength dispersive x-ray analyzer. The JEOL 100C (AEM) is equipped with a Devex 8000 EDX system. These facilities are used primarily for microstructural analysis and determination of crystal structures of fine phases present in metals and ceramics.

Mechanical Testing Laboratories

Experimental mechanical testing laboratories are available for teaching and research related to mechanical properties and deformation of metals, ceramics, and composite materials. Equipment available includes: Two compuer-controlled Instron 8502 Servo-Hydraulic Tension-Compression Systems with supporting grips, environmental chambers and furnaces; an Instron Model 4201 computerized tensile tester for high accuracy, low-load testing machine for ceramic materials, an ASCERA hydraulic tensile tester for brittle materials; two high-temperature and three room-temperature stress-rupture systems.

Polymer Engineering Laboratory

This laboratory is used for the synthesis, processing and testing of plastics. The equipment include: thermal analysis machines Perkin Elmer DSC 4, DSC 7, DTA 1400 and TGA 7, single screw table top extruder, injection molding facilities, polymer synthesis apparatus, oil bath furnaces, heat treating ovens and foam processing and testing devices.

Scanning Electron Microscope (SEM) Laboratory
Transmission Electron Microscope (TEM) Laboratory
Two scanning electron microscopes (SEM) an analytical scanning transmission (AEM) electron microscope, optical reflection and transmission microscopes, and supporting sample preparation and photographic equipment are the major facilities available for microstructural analysis. SEM's are available equipped with an Energy Dispersive X-ray (EDX) Analyzer, or equipped with stage-automated digital image analysis, a light element Quantum X-ray detector with a Kevex Delta System and a wavelength dispersive X-ray analyzer. The AEM is equipped with Kevex EDX system. These facilities are used primarily for microstructural analysis and determination of crystal structures of fine phases present in metals and ceramics.

Surface Metrology Laboratory
www.wpi.edu/TRAL
http://guinness.wpi.edu/~tral
The Surface Metrology Laboratory is dedicated to the study of surface textures, their creation and their influence of surface behavior or performance. We also study and design the manufacturing processes that create specific surface textures. We study and develop specialized algorithms that are used to support texture-related product and process design and to advance the understanding of texture dependent behavior. Our experience extends to analyzing data sets on scales from kiometers (earth's surface) to Angstroms (cleaved mica), although, the primary focus is on analyzing measured surfaces or profiles (i.e., topographic data) acquired from surfaces created or modified during manufacture, wear, fracture or corrosion.

The objective of the research on texture analysis is to develop characterization parameters that reduce large data sets, such as those acquired by atomic probe microscopy, scanning profiometry, confocal microscopy, or conventional profilometry. The purpose of the characterization parameters is to support product and process design or promote the understanding of adhesion, friction, wear, fracture, corrosion, or other texture related phenomena. The characterization parameters should have clear, physical interpretations for understanding the mechanisms which control surface behavior and surface creation. The laboratory also has experience with specialized image analyses, used, for example, to characterize the internal morphology of cermanic membrane.

X-Ray Diffraction Laboratory

Two fully automated and computerized x-ray diffractometers are available for teaching and research: a GE-XRD-5 diffractometer and a Nicolet 12/V polycrystalline diffraction system. In addition, a variety of software has been developed to utilize these instruments effectively. Currently, background modeling, peak searching, and curve fitting with deconvolution, are in use for quantitative phase analysis and residual stress analysis. A search of the JCPDS Powder Diffraction File is provided with the Nicolet system. A variety of x-ray cameras and gonioketers are available along with choice of x-ray tube targets to provide a wide x-ray diffraction capability. Additional support software is shared with the Electron Microscopy Facility to generate diffraction patterns for any crystal system in any desired orientation.

Degree Requirements

For the M.S.

For the master of science in materials science and engineering the student is required to complete a minimum of 30 credit hours. Requirements include at least three of the following four core courses: MTE 581, MTE 582, MTE 5810, MTE 583, one 4000- or 500-level mathematics course, 6 credit hours of thesis research, and three electives taken from materials engineering courses or any other graduate courses in science or mathematics, engineering approved by the student's advisor and the materials graduate committee.

Satisfactory participation in the materials engineering seminar (MTE 580) is also required for all full-time students. In addition to general college requirements, all courses taken for graduate credit must result in a QPA of 3.0 or higher. Waiver of any of these requirements must be approved by the materials science and engineering graduate committee, which will exercise its discretion in handling any extenuating circumstances or problems.

Examples of Typical Programs

Students with undergraduate background in materials engineering:

- Materials Engineering core courses - 12 credits
- Required math course - 3 credits
- Electives - 9 credits
- Seminar in materials engineering - 0 credits
- Thesis - 6 credits
- **Total: 30 credits**

Students with backgrounds in science, mathematics or another engineering discipline:

- ME 4840 Physical Metallurgy - 3 credits
- ME 4850 Solid State Thermodynamics - 3 credits
- Materials Engineering core courses - 12 credits
- Required math course - 3 credits
- Other electives - 3 credits
- Seminar in materials engineering - 0 credits
- Thesis - 6 credits
- **Total: 30 credits**

For the Ph.D.

The number of course credits required for the doctor of philosophy degree, above those for the master of science, is not specified precisely. For planning purposes, the student should consider a total of 21 to 30 course credits. The remainder of the work will be in research and independent study. The total combination of research and course work required will not be less than 60 credits beyond the master of science degree or not less than 90 credits beyond the bachelor's degree.

Admission to candidacy will be granted only after the student has satisfactorily passed the Materials Engineering Doctoral Qualifying/Comprehensive Examination (MEDQE). The purpose of this exam is to determine if the student's breadth and depth of understanding of the fundamental areas of materials engineering is adequate to conduct independent research and successfully complete a Ph.D. dissertation.

The MEDQE consists of both written and oral components. The written exam must be successfully completed before the oral exam can be taken. The oral exam is usually given within two weeks of the completion of the written exam. The MEDQE is offered one time each year.

A member of the materials science and engineering faculty will be appointed to be the chairperson of the MEDQE Committee. This person should not be the student's Ph.D. thesis advisor; but that advisor may be a member of the MEDQE Committee. Others on the committee should be the writers of the four sections of the examinations and any other faculty selected by the chairperson. Faculty from other departments at WPI or other colleges/universities, as well as experts from industry, may be asked to participate in this examination if the materials engineering faculty feels it is appropriate.

At least one year prior to completion of the Ph.D. dissertation, the student must present a formal seminar to the public describing the proposed dissertation research project. This Ph.D. Research Proposal will be presented after admission to candidacy.

All materials science and engineering students in the Ph.D. program must satisfactorily complete a minor in a program-related technical area. The minor normally consists of a minimum of three related courses and must be approved by the graduate study committee and the program head.

Admission Requirements

The program is designed for graduates with engineering, mathematics or science degrees. Some undergraduate courses may be required to improve the student's background in materials science and engineering.

As part of their graduate program, students are encouraged to elect courses from the various engineering, mathematics and science departments. The interdisciplinary aspects of materials science and engineering are emphasized. Please refer also to the programs in mechanical engineering and manufacturing engineering.

Mathematical Sciences

Programs of Study

The Mathematical Sciences Department offers three programs leading to the degree of master of science, a combined B.S./M.S. program, a program leading to the degree of master of mathematics for educators, and a program leading to the degree of doctor of philosophy.

The Master of Science in Applied Mathematics Program gives students a broad background in mathematics, placing an emphasis on areas with the highest demand in applications: numerical methods and scientific computation, mathematical modeling, discrete mathematics, optimization and operations research. In addition to these advanced areas of specialization, students are encouraged to acquire breadth by choosing elective courses in fields such as computer science, mechanical engineering and electrical and computer engineering, complementing their studies in applied mathematics. Students have a choice of completing their master's thesis or project in cooperation with one of the department's established industrial partners. The program provides a suitable foundation for the pursuit of a Ph.D. degree in applied mathematics or computer science, or for a career in industry immediately after graduation.

The Master of Science in Applied Statistics Program gives graduates the knowledge and experience to tackle problems of statistical design, analysis and control likely to be encountered in business, industry or academia. The program is designed to acquaint students with the theory underlying modern statistical methods, to provide breadth in diverse areas of statistics, and to give students practical experience through extensive application of statistical theory to real problems. Through the selection of elective courses, the student may choose a program with an industrial emphasis, or one with a more theoretical emphasis.

The combined B.S./M.S. program allows a student to work concurrently toward Bachelor and Master of Science degrees in Applied Mathematics and Applied Statistics.

Mathematics Certificate Program; knowledge of statistics equivalent to that provided by an introductory college statistics course required for the Industrial Statistics Certificate Program.)

• Industrial Mathematics
• Industrial Statistics

The Master of Mathematics for Educators is a two-year program designed primarily for secondary school mathematics teachers. The program provides teachers with an understanding of the fundamental principles of mathematics through courses and project work that model diverse pedagogical methods. All program requirements also incorporate appropriate technologies, as well as relevant results from research in mathematics education. The program emphasizes the teacher as a professional and educational leader through a variety of workshops, conferences and interactive experiences that provide graduates of the program with the expertise to become regional and national leaders in mathematics education.

The goal of the Doctor of Philosophy in Mathematical Sciences Program is to produce active and creative problem solvers, capable of contributing in academic and industrial environments. One distinguishing feature of this program is a 9 credit-hour project to be completed under the guidance of an external sponsor, either from industry or a national research center. The intention of this project is to connect theoretical knowledge with the relevant applications and to introduce the candidate to potential employers.

Faculty

H. F. Walker, Professor and Head; Ph.D. Courant Institute of Mathematical Sciences

P. W. Davis, Professor; Ph.D., Rensselaer Polytechnic Institute

M. Humi, Professor; Ph.D., Weizmann Institute of Science

R. Lipton, Professor; Ph.D., Courant Institute of Mathematical Sciences, New York University

R. Y. Lui, Professor; Ph.D., University of Minnesota

K. A. Lurie, Professor; Ph.D., A. F. Ioffe Physical- Technical Institute, Academy of Science, USSR

J. D. Petruccelli, Professor; Ph.D., Purdue University

D. Tang, Professor; Ph.D., University of Wisconsin

M. Chen, Associate Professor; Ph.D., Purdue University

P. R. Christopher, Associate Professor; Ph.D., Clark University

W. Farr, Associate Professor and Associate Head ; Ph.D., University of Minnesota

J. D. Fehribach, Associate Professor; Ph.D., Duke University

A. C. Heinricher, Associate Professor; Ph.D., Carnegie-Mellon University

B. Nandram, Associate Professor; Ph.D., University of Iowa

B. Servatius, Associate Professor; Ph.D., Syracuse University

D. Vermes, Associate Professor; Ph.D., University of Szeged, Hungary

B. Vernescu, Associate Professor; Ph.D., Institute of Mathematics, Bucharest, Romania

B. D. Doytchinov, Assistant Professor; Ph.D., Carnegie Mellon University

R. K. Jordan, Assistant Professor; Ph.D., University of Massachusetts

H. Kim, Assistant Professor; Ph.D., University of Wisconsin — Madison

C. J. Larsen, Assistant Professor; Ph.D., Carnegie Mellon Univeristy

M. Sarkis, Assistant Professor; Ph.D., Courant Institute of Mathematical Sciences

S. Weekes, Assistant Professor; Ph.D., University of Michigan

Research Interests

Active areas of research in the Mathematical Sciences Department include applied and computational mathematics, industrial mathematics, applied statistics, scientific computing, numerical analysis, ordinary and partial differential equations, nonlinear analysis, electric power systems, control theory, optimal design, composite materials, homogenization, computational fluid dynamics, biofluids, dynamical systems, free and moving boundary problems, porous media, turbulence and chaos, mathematical physics, mathematical biology, operations research, linear and nonlinear programming, discrete mathematics, graph theory, near ring theory, group theory, linear algebra, combinatorics, applied probability, stochastic processes, time series analysis, Bayesian statistics, Bayesian computation, survey research methodology, categorical data analysis, Monte Carlo methodology, statistical computing, survival analysis, model selection, and mathematics education.

Mathematical Sciences Computer Facilities

The Mathematical Sciences Department relies heavily on the use of modern computer facilities in the programs it offers. Current facilities include approximately 70 workstations, X-terminals, and PCs, as well as nine 500+ MHz DEC Alphas. In addition, department faculty and grauate students have access to the university's 16 mode (326 pu) IBM RS/6000 SP parallel computer. We are continually adding new resources and intend to maintain our position as one of the most heavily computerized mathematical sciences departments in the country.

Degree Requirements

For the M.S. in Applied Mathematics

The master's program in applied mathematics is a 36-credit-hour program. Students must complete the following seven core courses: Analysis I and II, Numerical Methods, Numerical Linear Algebra, Discrete Mathematics I, Mathematical Modeling and Stochastic Modeling. In addition, students are required to complete a 6-credit-hour master's Thesis or Project. The master's Thesis is an original piece of mathematical research work which focuses on advancing the state of the mathematical art. The master's Project consists of a creative application of mathematics to a real world problem. It focuses on problem definition and solution using mathematical tools.

The remaining three courses may be chosen from the graduate offerings of the Mathematical Sciences Department. Upper-level undergraduate mathematics courses, or a two-course graduate sequence in another department may be taken for graduate credit, subject to the approval of the departmental graduate committee. Candidates are required to successfully complete the Graduate Seminar MA 560.

For the M.S. in Applied Statistics

The master's program in applied statistics is a 36-credit-hour program. Courses taken must include MA 540, MA 541 andMA 558. In addition the student must complete a suitable 6-credit project, typically drawn from local business, industry or academia. Each student's program beyond the first semester must be approved in advance by the department's Graduate Committee. The remaining seven courses are normally chosen from the statistics/probability offerings of the Mathematical Sciences Department courses numbered MA 540, MA 558 plus MA 509. Upper-level undergraduate courses might be taken for graduate credit subject to the approval of the department's Graduate Committee.

For the Combined B.S./M.S. Programs in Applied Mathematics and Applied Statistics

A maximum of four courses may be counted towards both the undergraduate and graduate degrees. All of these courses must be 4000-level or above, and at least one must be a graduate course. Three of them must be beyond the 7 units of mathematics required for the B.S. degree.

Acceptance into the program means that the candidate is qualified for graduate school and signifies approval of the four courses, to be counted for credit towards both degrees. However, in order to obtain both undergraduate and graduate credit for these courses, grades of B or better have to be obtained.

For the Master of Mathematics for Educators

Candidates for the master of mathematics for educators degree must successfully complete 30 credit-hours of graduate study, including a 6 credit hour project (see MME 592, MME 594, MME 596). This project will typically consist of a classroom study within the context of a secondary mathematics course and will be advised by faculty in the Mathematical Sciences Department. Typically, a student will enroll in 4 credit-hours per semester during the fall and spring, with the remaining credit-hours taken in the summer. Normal degree completion time is two years, including two summers.

For the Ph.D.

The course of study leading to the doctor of philosophy in the mathematical sciences requires the completion of at least 60 credit hours beyond the master's degree, of which at least 30 credit hours must be directed toward independent research. The research preparation phase consists of:

- 9 to 15 credit hours of supervised independent study courses in the area of the candidate's specialization.
- 9 credit hours of the applied mathematics project (see description).
- At least 6 credit hours of courses, 500-level or higher in WPI departments outside of mathematical sciences.

Mathematical Sciences Ph.D. Project

As part of the research preparation phase, the student is encouraged to go off campus to complete a project sponsored by industry, national research laboratories or other approved external organizations. The project shall be in an area involving an application of mathematics or statistics. The scope of the project shall be equivalent to 9 credit hours of course work.

In the event that the student is unable to secure sponsorship through an off-campus organization, the student is required to complete an on-campus project in a department other than mathematical sciences.

Course of Study

Within the first year of enrollment, each student is expected to choose a specialization with his or her advisor, a plan of study must be submitted to and approved by the departmental graduate committee.

General Comprehensive Examination

In order to be admitted to candidacy, the student must take the General Comprehensive Examination at the beginning of the first year of study if entering with a master's degree, and no later than the beginning of the second year of study if entering with a bachelor's degree.

Admission to Candidacy

Admission to candidacy is granted when the student has passed the General Comprehensive Examination and has received approval of an application for admission to candidacy summarizing the student's planned course of study.

Ph.D. Preliminary Examination

Before registering for Ph.D. dissertation credits the candidate must pass the Ph.D. Preliminary Examination. This examination, which has both written and oral components, should be taken sometime during the second or third year after being admitted as a Ph.D. candidate.

Ph.D. Dissertation Proposal

At least six months prior to completion of the Ph.D. dissertation, the candidate must present a formal seminar to the public describing the proposed dissertation research project. A formal written research proposal must be submitted two weeks before the presentation.

Ph.D. Final Examination

With the dissertation and the other requirements of the program completed, the student is ready for the final oral defense. The student's Ph.D. thesis committee will determine by majority vote whether the student passes.

Ph.D. Thesis Committee

The student's dissertation advisor chairs the Ph.D. thesis committee. Under the direction of the advisor, the student selects the rest of the Ph.D. thesis committee. The committee must have at least five members; it should be made up of members of the mathematical sciences faculty and at least one faculty member from another department or one person from outside WPI who is a recognized expert in the area of the student's dissertation. This committee will participate in the Ph.D. dissertation proposal and the Ph.D. final examination. It is required that the committee be selected prior to the Ph.D. preliminary examination.

Admission Requirements

A basic knowledge of advanced analysis, linear algebra and differential equations is assumed for applicants to the master of science in applied mathematics. Students with serious deficiencies in these subjects may be required to enroll in supplementary courses on a non-credit basis. Typically, an entering master of science in applied statistics student will have an undergraduate major in the mathematical sciences, engineering or a physical science; however, individuals with other backgrounds will be considered. In any case, an applicant will need a strong background in mathematics which should include courses in advanced analysis and probability. Students with serious deficiencies may be required to correct them on a noncredit basis.

Candidates for the master of mathematics for educators degree must have a bachelor's degree and must possess a background equivalent to at least a minor in mathematics, including calculus and either teacher certification in mathematics or science or a full-time teaching position in one of these disciplines. Students are encouraged to enroll in courses on an ad hoc basis without official program admission. However, these students will not be eligible for any financial aid and must pay full tuition for each course. A typical student would complete the program in two years, taking one course each semester. However, the program can accommodate other completion schedules as well.

Mechanical Engineering

Programs of Study

The Mecahnical Engineering Department offers three graduate degree options,

- Master of Science
- Master of Engineering
- Doctor of Philosophy.

Areas of Research and Areas of Study

Active areas of research in the Mechanical Engineering Department include: theoretical, numerical, and experimental work in fluid mechanics, rarefied gas and plasma dynamics, solid and structural analysis, dynamics, vibrations, controls, biomechanics, engineering design, heat transfer, laser holography, aerospace engineering, and materials processing, manufacturing engineering and materials science.

The graduate curriculum is divided into five distinct areas of study:

- Fluids Engineering
- Dynamics & Controls
- Structures & Materials
- Design & Manufacturing
- Biomechanical Engineering

These areas of study reflect the research interests of the mechanical engineering faculty. In this way, graduate courses introduce students to fundamentals of mechanical engineering while simultaneously providing the background necessary to become involved with the ongoing research of the Mechanical Engineering faculty.

Mechanical Engineering Laboratories

The Mechanical Engineering Department at WPI provides a multi-disciplinary research and education environment combining elements of mechanical engineering, manufacturing engineering, and materials science. Most of the department's facilities are housed in Higgins Laboratories, the principle building of the department. Research laboratories associated with the Materials Science and Engineering program, as well as the Manufacturing Engineering program, are located in Washburn Shops.

The following facilities are housed in Higgins Laboratories:

Aerospace Laboratory

This laboratory includes an ultra-quiet low turbulence, closed circuit, subsonic wind tunnel. This fixed facility utilizes removable test sections of approximately 3x4 feet cross section and is capable of speeds up to 350 mph. By using a substantive turbulence management system along with integral acoustic treatment, the tunnel is one of the highest quality facilities available. Another major element of this laboratory is a blow-down supersonic wind tunnel. It uses evacuated and pressurized vessels connected by a 6x6 inch test section capable of speeds up to Mach 3 for short intervals of time. Additionally, workshop areas are provided for model preparation and smaller scale experiment development.

Computational Gas and Plasma Lab

Space science and engineering research areas in CGPL include: electric propulsion, neutral and plasma plumes, spacecraft-induced environment interactions, micropropulsion, rarefied gasdynamics, magnetogasdynamics, and microgravity fluid dynamics. The efforts in CGPL encompass modeling in close interaction with ground and space experiments, data analyses and design of experiments. CGPL participates in national and international space programs and provides unique opportunities to graduate and undergraduate students with aerospace interests. Infrastructure at CGPL includes several multi-processor NT workstations, UNIX workstations, peripherals, visualization and data reduction software.

Fluid Dynamics Laboratory

This laboratory provides experimental facilities and instrumentation for experimental activities in the area of fluid dynamics. A small, open-return subsonic wind tunnel, a blow-down supersonic tunnel, hot wire anemometry system, laser doppler system, computer data acquisition systems, and high speed flow visualization systems are available. Separate areas are provided for model preparation and small-scale experiments.

Heat Transfer Laboratory

This laboratory provides work stations and experimental facilities for general areas of heat transfer and combustion.

Hydrodynamics Laboratory

This laboratory provides experimental facilities and instrumentation for measurement of liquide flow phenomena. A closed-circuit free surface water tunnel with a 2 ft. by 2 ft. test section and vertical water tank are available. These facilities are primarily for flow visualization and are supported by data acquistion systems and various flow measurement devices.

Dynamic Simulation Laboratory (DYSIM Lab)

This laboratory is a general purpose PC laboratory which exposes large numbers of students to modern dynamic and geometric simulation techniques. Although this laboratory primarily supports undergraduates, it is available to graduate students. Students use the DYSIM Lab to perform simulated experiments and observe demonstrations of course topics. The lab is equipped with 40 state-of-the-art PCs which are connected through the computational network and direct links to other design process components.

Vibrations, Controls, and Dynamics Laboratory

One of the growing fields in Mechanical Engineering is the multi-disciplinary area of Vibrations-Controls-Dynamics with applications in numerous fields such as earthquake engineering, vibration and acoustic isolation, rotor dynamics, and controls/systems engineering. This facility which is equipped with the state-of-the-art equipment support educational, project, and research activities in the area of vibrations and controls. This is also a teaching facility for the courses in Vibrations and Controls. Some of the equipment in this laboratory includes signal analyzers, a 100 lb. Shaker table, and computational hardware and software for various vibration/controls applications.

Center for Holographic Studies and Laser Technology, (CHSLT)

CHSLT currently consists of ten laboratories furnished with state-of-the-art facilities which are used for both research and educational activities. These labs within CHSLT include:

- Center for Nanotechnology and Micromechatronics
- Engineering and instrument development lab
- Fiber optic preparation lab
- Multifunctional laser image processing lab
- Nano indentor laser lab
- Stroboscopic heterodyne lab
- Fiber optic laser lab
- Ruby laser lab
- Holographic lab
- Coherent laser lab

These laser laboratories are equipped with several systems utilizing He-Ne, Ar-ion, and Nd: YAG lasers. They are supported by a self-contained network of computers and peripheral facilities, as well as supporting instrumentation systems. The lasers, computers and supporting instrumentation are used in studies of fundamental phenomena governing high energy-density interactions in thin film imaging, with powder metal materials, plastics, ceramics, and composites, micromachining, underwater propagation, holography, displacement and strain measurement, vibrations, fracture mechanics, mathematical modeling, numerical computations, and applications to other problems of modern science, engineering and technology.

Keck Design Center — The Design Studios

These laboratories provide a prototype facility which consists of a design studio and a prototype production facility, linked by computational equipment, and 20-30 high-end workstations with software support for video-picture-within-the-monitor-teleconferencing, provide two-way communication of audio, video, and data between the Design Studios, and off-campus sites. In the computationally-equipped studio, students have clustered seating about multiple workstations and discuss and/or analyze with remote sponsors or others in real time as changes are made. Part files can be ported to rapid prototyping machines or lithography units within the Design Center and beyond. Video cameras at the prototyping stations show the real-time fabrication within a window on the workstations.

Biomechanical Engineering Laboratory

This laboratory provides experimental and computational facilities for research in the area of biomechanics and biofluids. Facilities include a hot wire anemometry system, PC-based computational facilities, and ancillary equipment. This laboratory is also equipped with anatomical dissection facilities, kinematic data acquistion systems, instrumentation for measuring acceleration, velocity, force and pressure, and computer data acquistion systems. This facility serves for teaching and research in biomechanics, biofluids, and biodynamics.

Rehabilitation Engineering Laboratory

This laboratory is concerned with the development of equipment needed in research in the area of rehabilitation and aiding the handicapped. Typically, the subjects studied are mobility aids for handicapped children, and augmentative communication and mobility systems. The laboratory has a variety of instruments for stress measurements in prostheses. This laboratory has close ties with the University of Massachusetts Rehabilitation Center and Hospital, and several joint projects are currently in progress.

Engineering Experimentation Laboratory

This laboratory provides opportunity to use computerized data acquistion systems and devices in actual experiments. Experimental measurements in the areas of heat transfer, flow measurement and visualization, force/torque/strain measurements, motion and vibration measurments, laser applications, and other selected topics are available.

The following laboratories are operated by M.E. faculty, but they are primarily concerned with materials science and engineering. Full descriptions of these laboratories are described in Materials Science and Engineering section of the catalog.

- **Electrochemistry, Tribology and Corrosion laboratories**
- **Mechanical Testing Laboratories**
- **Metal Processing Institue (MPI)**
  1. Alumium Casting Research Lab
  2. Powder Metallurgy Research Center
  3. Semisolid Materials Processing Lab
  4. Center for Heat Treating Excellence
  5. Two complimentary core labs NonDestructive Evaluation Lab and;
  6. Economic Modeling & Forecasting lab
- **NMR Spectroscopy Laboratory**
- **Optical and Electron Metallography Laboratories**
- **X-Ray Diffraction Laboratory**

The following laboratories are operated by M.E. faculty, but they are primarily concerned with manufacturing. Full descriptions of these laboratories are described in the Manufacturing Engineering section of the catalog.

- **Computer Integrated Manufacturing Laboratory**
- **Robotics Laboratory**

Faculty

R. D. Sisson Jr., Interim Head, Materials Science and Engineering Program Head, Ph.D., (Purdue University), Structures & Materials, Manufacturing & Design

Professors

A. N. Alexandrou, Director of Semi-Solid Processing Lab., MPI, Ph.D., (University of Michigan), Computational Fluid Dynamics, Materials Processing

D. Apelian, Howmet Professor of Engineering; Director of Metal Processing Institute (MPI); Sc.D., (Massachusetts Institute of Technology) Materials Engineering, Solidification, Aluminum Casting, Powder Matallurgy, Metal Processing

R. R. Biederman , George F. Fuller Professor; Ph.D., (University of Connecticut), Materials Engineering

M. F. Dimentberg, Ph.D., (Moscow Institute of Power Engineering), Random Vibrations, Nonlinear Dynamics, Controls, Mechanical Signature Analysis

W. W. Durgin, K. G. Merriam Professor and Associate Provost; Ph.D., (Brown University), Fluid Mechanics, Aerodynamics, Fluid-Structure Interactions

R. R. Hagglund, Ph.D., (University of Illinois), Analytical Dynamics, Solid Mechanics

A. H. Hoffman, Ph.D., (University of Colorado), Biomechanics, Bioengineering, Rehabilitation Engineering

R. Ludwig, Ph.D., (University of Colorado), Electrical & Computer Engineering, E&M Fields, NDE

R. L. Norton, M.S., (Tufts University), Machine Design, Kinematics, Vibrations

R. J. Pryputniewicz, Director of the Center for Holographic Studies and Laser Technology; Ph.D., (University of Connecticut), Laser Metrology, Micro-Mechanics, Electro-mechanical systems

J. J. Rencis, Ph.D., (Case Western Reserve University), Boundry- and Finite-Element Methods, Computational Mechanics

B. J. Savilonis, Ph.D., (State University of New York, Buffalo), Biofluid Mechanics, Fire Modeling

J. M. Sullivan, Jr., D.E., (Thayer School of Engineering, Dartmouth College), Numerical Analysis, Mesh Generation, CAD

Associate Professors

H. K. Ault, Ph.D., (WPI), CAD, Engineering Design, Graphics

J. Barnett, Ph.D., (WPI), Fire Protection Engineering

I. Bar-On, Ph.D., (Hebrew University of Jerusalem), Fracture Mechanics, Fatigue, Autoadaptive Materials

C. A. Brown, Ph.D., (University of Vermont), Materials Processing and Manufacturing, Biomechanics, Surface Metrology, Fractal Analysis

C. D. Demetry, Ph.D., (Massachusetts Institute of Technology), Ceramics, Electronic Materials.

N. A. Gatsonis, Ph.D., (Massachusetts Institute of Technology), Fluids Engineering, Computational Rarefied Gasdynamics, Magnetogasdynamics, and Microgravity Fluid Dynamics

J. C. Hermanson, Ph.D., (California Institute of Technology), Experimental Fluid Mechanics, Combustion, Heat Transfer

Z. Hou, Ph.D., (California Institute of Technology), Random Vibrations, Structural Control, Autoadaptive Structures

H. Johari, Ph.D., (University of Washington), Experimental Fluid Mechanics, Turbulence, Aerodynamics

M. M. Makhlouf, Director of Aluminum Casting Laboratories, MPI, Ph.D., (WPI) Aluminum Casting, Heat Treating of Metals

Y. Rong, Ph.D., (University of Kentucky), CAM, CAD, Computer-Aided Fixture Design, Precision Engineering, Manufacturing Dynamics and Control

D. J. Olinger, Ph.D., (Yale University), Fluid Dynamics, Fluid-Structure Interaction

M. W. Richman, Ph.D., (Cornell University), Dynamics of Granular Flows, Powder Mechanics

S. Shivkumar, Ph.D., (Stevens Institute of Technology), Biomaterials, Polymers, Aluminum Casting

Assistant Professors

M. Demetriou, Ph.D., (University of Southern California), Systems and Control, Structural/Acoustic Control, Fault Detection/Diagnosis

M. S. Fofana, Ph.D., (University of Waterloo), CAM, Axiomatic Design

S. S. Kohles, Ph.D., (University of Wisconsin at Madison), Biomedical and Clinical Engineering

Non Tenure Track

L. Arnber, Adjunct Affliate Professor, MPI

A. Bratus, Adjunct Professor

E. Cobb, Visiting Assistant Professor; Ph.D., (University of Connecticut), Manufacturing & Design

E. Eckert, Adjunct Affliate Professor, MPI

V. Entov, Ph.D., Adjunct Professor

B. Ghassemi, Visiting Assistant Professor

P. Grigg, Ph.D., Adjunct Professor

U. Gummeson, Director of Powder Metallurgy Research Center, MPI

J. R. Hall, Adjunct Professor, Ph.D., (University of Florida, Gainesville), Dynamics & Structures

R. N. Katz, Norton Research Professor; Ph.D., (Massachusetts Institute of Technology), Structure & Materials

S. Makarov, Research Professor; Ph.D., MPI

S. Mirza, Professor of Practice, Director of Manufacturing Engineering; Ph.D., (University of Wisconsin, Madison), Dynamics of Composites, Finite Element Techniques

L. Wang, Research Scientist, MPI

Emeritus

J. M. Boyd, Professor

H. T. Grandin, Professor

W. A. Kistler, Professor

J. A. Mayer, Jr., Professor

K. E. Scott, Professor and Department Head

C. W. Staples, Professor

L. C. Wilbur, Professor

D. N. Zwiep, Professor and Department Head

Degree Requirements

M.S. Degree

In addition to the WPI requirements, the course of study leading to the master of science (thesis-option) degree in mechanical engineering requires the completion of at least 30 graduate credit hours. A minimum of 24 credits must be devoted to course work, and at least 6 credit hours must be devoted to thesis research. The result of the research credits must be a completed master's thesis. Except for certain courses taken by students in the B.S./M.S. program, no undergraduate courses may be counted toward graduate credit.

Each student must select a major area of study from the following: Fluids Engineering; Dynamics & Controls; Structures & Materials; Manufacturing & Design; Biomechanical Engineering. The required program of study leading to the master of science degree has the following format:

Course Work

- 9 graduate course credits in the major area of study
- 3 graduate course credits in a second M.E. area of study

- 3 graduate course credits in a third M.E. area of study
- 3 graduate course credits in math taken from the Math department
- 6 graduate course credits of electives within or outside of M.E
- 6 graduate thesis credits
- **Total — 30 credits (minimum requirements)**

In addition to the standard courses listed in this catalog, students may receive credit for special topics under ME 593 or independent study under ISP. Faculty members often experiment with new courses under the heading of ME 593, although no course may be offered more than twice in this manner.

Academic Advising

Upon admission to the master's program each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. The arrangement of this plan should be scheduled before the first day of registration.

Prior to registering for any additional credits, the student must identify a permanent thesis advisor who assumes the role of academic advisor and with whom a suitable thesis topic and the remaining course of study are arranged. The plan of study must be approved by the Mechanical Engineering Graduate Committee. Prior to completing 18 credits, the student must form a thesis committee that consists of the thesis advisor and at least two other WPI faculty members with expertise/ knowledge of the thesis topic.

Schedule of Academic Advising

Temporary Advisor: Meets with student prior to first registration to plan first 9 credits of study.

Thesis Advisor: Selected by student prior to registering for more than 9 credits.

Program of Study: Arranged with thesis advisor prior to registering for more than nine credits.

Thesis Committee: Formed by student prior to registering for more than 18 credits. Consists of the thesis advisor and at least two other M. E. faculty members.

This schedule ensures that students are well advised and actively engaged in their research at the early stages of their programs.

Thesis Defense

Each master candidate must defend his/her research during an oral defense, which is administered by an examining committee that consists of the thesis committee and a representative of the M. E. graduate committee who is not on the thesis committee. The defense is open to public participation and consists of a 30-minute presentation by the student followed by a 30-minute open discussion. At least one week prior to the defense each member of the examining committee must receive a copy of the thesis. One additional copy must be made available for members of the WPI community wishing to read the thesis prior to the defense and public notification of the defense must be given by the M. E. graduate secretary. The examining committee will determine the acceptability of the student's thesis and oral performance. The thesis advisor will determine the student's grade.

M.Eng. Degree

In addition to the WPI requirements, the course of study leading to the master of engineering (non-thesis option) degree in mechanical engineering requires the completion of at least 30 graduate credit hours. A maximum of 3 credits may be devoted to directed research (ME 598). Directed research can take the form of a project proposed by the student, completed under the guidance of a faculty member, and, if possible, done in collaboration with an industrial contact. Each student must select a major area of study from the following: Fluids Engineering; Dynamics & Controls; Structures & Materials; Manufacturing & Design; Biomechanical Engineering. The required program of study leading to the master of engineering degree has the following format:

Course Work

- 12 graduate course credits in the major area of study (3 of which can be directed research)
- 3 graduate course credits in a second M.E. area of study
- 3 graduate course credits in a third M.E. area of study
- 3 graduate course credits in math taken from the Math department
- 9 graduate course credits of electives within or outside of M.E.
- **Total — 30 credits (minimum requirements)**

In addition to the standard courses listed in this catalog, students may receive credit for special topics under ME 593 or independent study under ISP. Faculty members often experiment with new courses under the heading of ME 593, although no course may be offered more than twice in this manner.

Academic Advising

Upon admission to the master's program each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. The arrangement of this plan should be scheduled before the first day of registration.

Prior to registering for any additional credits, students must identify a permanent academic advisor with whom the remaining course of study is arranged. The plan of study must be approved by the Mechanical Engineering Graduate Committee.

Schedule of Academic Advising

Temporary Advisor: Meets with student prior to first registration to plan first 9 credits of study.

Academic Advisor: Selected by student prior to registering for more than 9 credits.

Program of Study: Arranged with academic advisor prior to registering for more than 9 credits.

This schedule ensures rational course selection, and provides the student with a faculty contact with whom all academic concerns can be addressed.

Changing Master's Programs

Students in the M.Eng. program may switch into the M.S. program at any time by notifying the Mechanical Engineering Graduate Committee of the change, provided that they have identified a thesis advisor, formed a thesis committee, and have worked out a plan of study with their thesis advisor. In the case of such a transfer, all credits (including directed research) earned in the M.Eng. program automatically will be transferred to the M.S. program. Subjected to the thesis advisor's approval, directed research credits (ME 598) earned in the M.Eng. program may be transferred to thesis research credits (ME 599) in the M.S. program.

Any student in the M.S. program may request a switch into the M.Eng. program by submitting the request in writing to the Mechanical Engineering Graduate Committee. Before acting on such a request, the Mechanical Engineering Graduate Committee will require and seriously consider written input from the student's thesis advisor. Departmental financial aid given to the M.S. students who are permitted to switch to the M.Eng. program will automatically be withdrawn. Subject to the approval of the Mechanical Engineering Graduate Committee, a maximum of 3 credits of thesis research (ME 599) earned by a student in the M.S. program may be transferred to directed research credit (ME 598) in the M.Eng. program.

Ph.D. Degree

In addition to the WPI requirements, the course of study leading to the doctor of philosophy in mechanical engineering requires the completion of at least 60 credit hours beyond the master degree, of which at least 30 credit hours must be directed toward independent research. Although the number of course credits is not specified, the student is expected to complete at least seven to ten technical courses. These should include at least three related courses that are chosen outside the area of research. The result of the research credits must be a completed doctoral dissertation. A typical program of study leading to the doctor of philosophy has the following format:

Course Work

- 12 (required) to 21 (maximum) graduate course credits related to research area
- 9 (required) graduate course credits outside of research area
- 30 (required) to 39 (maximum) graduate credits for independent research (ME 698 and ME 699)
- **Total: 60 credits (required)**

Prior to admission to candidacy, a student may receive up to 18 credits of pre-dissertation research under ME 698. Only after admission to candidacy may a student receive credit toward dissertation research under ME 699. Students may receive credit for special topics under ME 593 or independent study under ISP.

Diagnostic Background Review

During their first semester of enrollment in the doctoral program, all students are required to demonstrate a reasonable background in applied mathematics and in four of the following seven additional subject areas: dynamics and vibrations; experimentation; fluid mechanics, materials science; numerical methods; solid mechanics, and thermodynamics and heat transfer. The mechanical engineering graduate committee will review the transcripts and supporting materials of each doctoral student in order to determine those areas in which further course work is necessary to satisfy this requirement.

Academic Advising

Upon admission to the doctoral program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. The arrangement of this plan should be scheduled before the first day of registration.

Prior to registering for any additional credits, the student must identify a permanent dissertation advisor who assumes the role of academic advisor and with whom a suitable dissertation topic and the remaining course of study are arranged. The plan of study must be approved by the Mechanical Engineering Graduate Committee. Prior to completing 18 credits, the student must form a dissertation committee that consists of the dissertation advisor, at least two other M.E. faculty members and at least one member from outside the department. These committee members should be selected because of their abilities to assist in the student's dissertation research.

Schedule of academic advising:

Temporary Advisor: Meets with student prior to first registration to plan first 9 credits of study.

Dissertation Advisor: Selected by student prior to registering for more than 9 credits.

Program of Study: Arranged with dissertatiion advisor prior to registering for more than 9 credits.

Dissertation Committee: Formed by student prior to registering for more than 18 credits. Consists of the dissertation advisor and a least two other M.E. faculty and a least 1 outside member.

This schedule ensures that students are well advised and actively engaged in their research at the early stages of their programs.

Admission to Candidacy

Admission to candidacy will be granted when the student has satisfactorily passed a comprehensive examination intended to measure ability in designated curriculum areas. The details of the examination procedure can be obtained from the Mechanical Engineering Graduate Committee. This examination, which has both written and oral components, should be taken after the student has completed a significant portion of course work and must be taken at least nine months prior to the final dissertation defense. The comprehensive exam is administered by all members of the dissertation committee and by a representative of the mechanical engineering graduate committee who is not a member of the dissertation committee. A student may take the exam no more than twice.

Doctoral Research Proposal

Each student must prepare a written proposal that describes the anticipated doctoral research and places it in the context of the current literature. The proposal must be submitted to and approved by the dissertation committee at least one year before the completion of the dissertation, and is ordinarily submitted soon after admission to candidacy is granted. A copy of the approved proposal should be maintained in the student's departmental file.

Dissertation Defense

Each doctoral candidate is required to defend the originality, independence, and quality of research during an oral dissertation defense that is administered by an examining committee that consists of the dissertation committee and a representative of the mechanical engineering graduate committee who is not on the dissertation committee. The defense is open to public participation and consists of a one hour presentation by the student followed by a one hour open discussion. At least one week prior to the defense, each member of the examining committee must receive a copy of the dissertation. One additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense and public notification of the defense must be given by the mechanical engineering graduate secretary. The examining committee will determine the acceptability of the student's dissertation and oral performance. The dissertation advisor will determine the student's grade.

The Combined Bachelor's/Master's Programs

The Mechanical Engineering Department offers both B.S./M.S. and B.S./M.Eng. programs for currently enrolled WPI undergraduates. The Department's rules for these programs vary somewhat from the Institute's rules.

For students in the B.S./M.S. and B.S./M.Eng. programs a minimum of two courses and a maximum of four courses may be counted toward both the undergraduate and graduate degrees. Regardless of how many are counted toward both degrees, at least two must be graduate courses (including graduate-level independent study courses), and none may be lower than the senior-level. A grade of B or better is required for any course to be counted toward both degrees.

The application for the Combined B.S./M.S. or B.S./M.Eng. Program must include a list of four courses that the applicant proposes to count toward both their undergraduate and graduate degrees. In most cases, the list consists of courses that the applicant will take in the senior year.

Applications will not be considered if they are submitted prior to the second half of the applicant's junior year. Ideally, applications (including recommendations) should be completed by the first week of the last term (usually D-term) of the junior year.

Acceptance into either the B.S./M.S. or B.S./M/Eng. program means that the candidate is qualified for graduate school, and signifies approval of the four courses listed for credit toward both the undergraduate and graduate degrees. However, admission is contingent upon the completion of two graduate courses (from the submitted list) with grades of B or better in each. If grades of C or lower are obtained in any other listed courses, then they are not counted toward the graduate degree, but the applicant is still admitted in to the program.

Students in the B.S./M.S. program are strongly encouraged to pick a thesis area of research that is closely related to the subject of their Major Qualifying Project. Those students in the B.S./M.S. program who complete their B.S. degrees in May are encouraged to begin their thesis research during the summer immediately following graduation.

A detailed written description of the Combined B.S./M.S. and B.S./M.Eng. Programs in mechanical engineering can be obtained from the mechanical engineering graduate secretary.

Admission Requirements

For the M.S. and M.Eng. Programs, applicants should have a B.S. in mechanical engineering or in a related field (i.e., other engineering discipline, physics, mathematics, etc.).

The standards are the same for admission into the M.S. and M.Eng. programs. At the time of application to the master's level graduate program, the student must specify interest in pursuing either the M.Eng. or M.S. degree.

For the Ph.D., a master's degree in mechanical engineering or in a related field (i.e., other engineering discipline, physics, mathematics, etc.) is required.

The Mechanical Engineering Department reserves its financial aid for graduate students in the M.S. and Ph.D. programs only.

Physics

Programs of Study

WPI physics graduate programs prepare students for careers in research which require a high degree of initiative and responsibility. Prospective employers are industrial laboratories, government or non-profit research centers, or colleges and universities.

WPI's physics courses are generally scheduled during the day but with sufficient flexibility to accommodate part-time students. Special topics courses in areas of faculty research interest are often available.

Faculty

T. H. Keil, Professor and Head; Ph.D., University of Rochester

S. N. Jasperson, Professor; Ph.D., Princeton University

D. F. Nelson, Research Professor; Ph.D., University of Michigan

G. D. J. Phillies, Professor; D.Sc., Massachusetts Institute of Technology

L. R. Ram-Mohan, Professor; Ph.D., Purdue University

A. Walther, Professor; Ph.D., Technical University of Delft, Holland

P. K. Aravind, Associate Professor; Ph.D., Northwestern University

N. A. Burnham, Associate Professor; Ph.D., University of Colorado

R. S. Quimby, Associate Professor; Ph.D., University of Wisconsin, Madison

G. A. Swartzlander, Associate Professor; Ph.D., Johns Hopkins University

G. S. Iannacchione, Assistant Professor; Ph.D., Kent State University

L. C. Lew Yan Voon, Assistant Professor; Ph.D., WPI

S. W. Pierson, Assistant Professor; Ph.D., University of Minnesota

A. Zozulya, Assistant Professor; Ph.D., Lebedev Physics Institute

Research Interests

Chemical and biochemical physics: diffusion and transport in liquids, light scattering spectroscopy, and multidetector correlation spectroscopy.

Materials research: magnetic materials and ferroelectrics, amorphous and glassy substances, low-temperature properties, diluted magnetic semiconductors, semiconductor superlattices, and polymer and biomacromolecule solutions.

Classical and quantum optics: Fourier optics, photon statistics, nonlinear optics, fiber optics, coherent states and squeezed states, photoacoustic spectroscopy, optical properties of rough surfaces and of thin metal films, metrology and design of optical instruments, laser spectroscopy of impurity ions in glasses, development of infrared fiber lasers, quasielastic light scattering, inelastic light scattering and excitation spectroscopy of superlattices, and color center lasers.

Solid state physics: optical properties of semiconductor superlattices and quantum wells, Brillouin scattering near phase transitions, high field surface conduction in semiconductors, low-temperature properties of glassy and amorphous materials, magnetic and nonmagnetic impurities randomly distributed in solids, magnetic properties of rare-earth mixtures, ordering of random dipolar and strain defects, semiconductor devices, and modulation spectroscopy applied to thin films and to surface phenomena.

Statistical mechanics: magnetic systems, cooperative phenomena and phase transitions, properties of chains interacting via strain-strain and electric dipole interactions, relaxation phenomena in disordered systems, and transport and equilibrium properties of liquids, solutions and polymer melts.

Faculty Research Interests

P. K. Aravind, Theoretical non-linear and quantum optics.

N. A. Burnham, Atomic force microscopy, nanomechanics.

S. N. Jasperson, Optical properties of solids, optical instruments.

T. H. Keil, Solid state physics, mathematical physics, fluid mechanics.

D. F. Nelson, Optical and transport properties of semiconductors, solid state physics experiment and theory.

G. S. Iannacchione, Calorimetry, liquid crystals, phase transitions.

A. A. Zozulya, Non-linear optics, photorefractive materials, atom pipes.

S. W. Pierson, Statistical mechanics, High-T superconductors, vortices.

L. C. Lew Yan Voon, Solid state physics, super lattices in semi conductors.

G. D. J. Phillies, Light scattering spectroscopy, biochemical physics, polymers.

R. S. Quimby, Optical properties of solids, laser spectroscopy, fiber optics.

L. R. Ram-Mohan, Field theory, many-body problems, solid state physics.

G. A. Swartzlander, Nonlinear optics, solitons and other self-organizing structures, nonlinear materials, computer-generated holography, image and signal processing.

A. Walther, Optics, optical instruments, precision measurements.

Degree Requirements

For the M.S.

The M.S. degree in physics requires 30 semester hours of credit: 6 or more in thesis research and the remainder in approved courses and independent studies, to include PH 511, PH 514, PH 515, PH 522, and PH 533 (15 semester hours). Although a thesis defense is not required, students nearing completion of the M.S. program are required to present a seminar based on their thesis research.

For the Ph.D.

The doctor of philosophy degree 90 credit hours are required, including 42 in approved courses or directed study (which must include PH 511, PH 514-515, PH 522 and PH 533, or their equivalents), 30 of dissertation research, and completion and defense of a Ph.D. thesis. Courses taken to satisfy M.S. degree requirements may be counted against the required 42 credits of courses, but completion of a M.S. degree is not required.

One year of residency and passage of a qualifying examination are required.

General Information

The qualifying examination for the doctor of philosophy degree is usually administered each year at the beginning of the second semester. Ph.D. aspirants who enter after the bachelor's degree may take the examination during their first year of graduate school, and are expected to take the examination by the end of their second year. There is no penalty for failing or not taking the examination during the first year. Students who fail the examination during their second year must pass the examination when it is next offered. The qualifying examination will include, but is not limited to, material taken from PH 511, PH 514-515, PH 522 and PH 533.

Each student's academic work is reviewed on an annual basis by the Physics Department graduate committee. Continuation of student status is based on satisfactory progress toward a degree, both in terms of course work and of research. Renewals of research and teaching assistantships are dependent on satisfactory performance of required duties.

Admission Requirements

B.S. in physics preferred, however applicants with comparable backgrounds will also be considered.

Course Descriptions

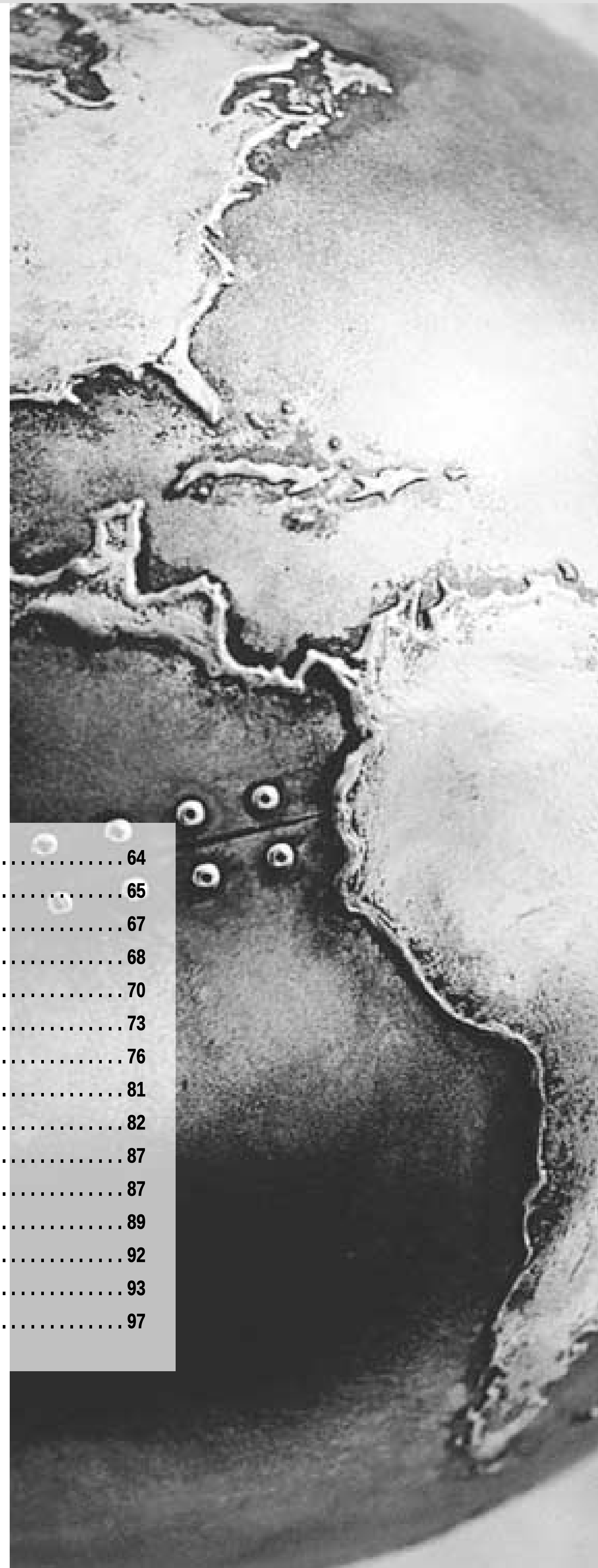
The following is a listing of all courses available through WPI's graduate science, engineering and management programs. The course schedule for the current academic year is outlined in a separate brochure and available at our website: www.wpi.edu. This schedule, available upon request from the Graduate Admissions Office or the Projects and Registrar's Office, is subject to change and registrants should consult the final schedule before completing any registration forms. If there is sufficient interest in a course not scheduled for a particular semester, WPI will consider offering the course. All course offerings are subject to a minimum enrollment.

Most evening courses meet one evening per week; where noted, a twilight course may meet twice each week for a semester.

Thesis, project or directed research is available in degree programs. Special topics courses or independent study are not always listed since they are on an as arranged basis which must be made prior to registration.

The number of courses offered each year may be limited in some disciplines; the schedule of courses over a period of time generally allows a student taking four courses per semester to complete degree requirements for the master's degree in about two years and students taking two courses per semester to complete requirements in three to four years.

All courses are 3 credits unless otherwise noted.



Biology & Biotechnology 64
Biomedical/Clinical Engineering 65
Chemical Engineering 67
Chemistry & Biochemistry 68
Civil & Environmental Engineering 70
Computer Science 73
Electrical & Computer Engineering 76
Fire Protection Engineering 81
Management 82
Manufacturing Engineering 87
Materials Science & Engineering 87
Mathematical Sciences 89
Mathematics for Educators 92
Mechanical Engineering 93
Physics 97

BIOLOGY & BIOTECHNOLOGY

BB 501. Seminar

1 credit per semester

BB 502. Techniques in Electron Microscopy

This course presents the theory of operation, applications, and use of scanning and transmission electron microscopy in biology. Recent original articles from the biological literature illustrate the applications of these techniques to research. Students prepare specimens for both kinds of electron microscopes and employ the standard preparative techniques including fixation, dehydration, staining, critical point drying, vacuum evaporation, embedding and sectioning. Associated photographic methods are also introduced.

BB 505. Fermentation Biology

Focuses on biological (especially microbiological) systems by which materials and energy can be interconverted (e.g. waste products into useful chemicals or fuels). The processes are dealt with at the physiological and the system level, with emphasis on the means by which useful conversions can be harnessed in a biologically intelligent way. The laboratory focuses on measurements of microbial physiology and on bench-scale process design.

BB 507. Cell Culture

The use of cultured animal cell systems for research and production will be explored. Concepts, including media design, the effects of extracellular matrices, scaling up of cell cultures, and biochemical and morphologic assessment of cell function, will be discussed as a basis for reading from the literature.

BB 509. Scale-Up of Bioprocessing

Strategies for optimization of bioprocesses for scale-up applications. In addition to the theory of scaling up unit operations in bioprocessing, students will scale-up a bench scale bioprocess (5 liters) including fermentation and downstream processing to 55 liters. Specific topics include the effects of scaling-up on: mass transfer and bioreactor design, harvesting techniques including tangential flow filtration and centrifugation, and chromatography (open column and HPLC). (Prerequisites: BB 4050/505 and BB 4060/560 as a working knowledge of the bench scale processes will be assumed. Otherwise, instructor permission is required.)

BB 510. Advanced Microbial Genetics

A study of modern molecular genetics as revealed by studies of microbial systems. This course covers detailed structure/function relationships in nucleic acids and proteins; molecular mechanisms of DNA replication and expression; mutagenesis, recombination, transposition, transformation, conjugation and repair; and molecular biology of plasmids and phages.

BB 520. Immunology

This is a survey course in immunology which assumes a background in cell biology, genetics and biochemistry. Topics to be covered will include cells of the immune system, antigen/antibody immunochemistry, immunogenics and immune responses. Readings from the research literature will be assigned.

BB 542. Ecological Simulation Modeling

This course will cover computer simulation modeling of populations, bioenergetics, behavior of individuals, and ecosystem dynamics. Modeling techniques covered will range from simple linear models of populations and interactions between ecosystem components to individual-based models of populations in complex environments. Students successfully completing the course should be capable of understanding models used in today's study of populations and ecosystems and of developing original models. Knowledge of a programming language is assumed.

BB 544. Bioinformatics

This course will focus on the field of Bioinformatics. After providing an overview of biological data such as DNA and protein sequences, genetic markers and providing a summary of population genetics concepts, the course will cover various methods of computational genetic analysis. Students will learn about DNA and protein sequence analysis, gene mapping, evolutionary analysis, molecular biology databases, analysis of expression data and microarray analysis.

BB 545. Advanced Cell Biology

Selected readings from the scientific literature are used to illustrate milestones of cell biology, state-of-the-art cellular lab techniques, and experimental design. The course emphasizes the various approaches to study cell structure, function and the mechanisms by which cells reproduce, develop and interact.

BB 549. Molecular Biology

Synthesis of biologically important macromolecules. Selected readings from the scientific literature are used to illustrate the milestones of molecular biology and the development of techniques and experiments. Protein synthesis and ribosome structure lead into a discussion of RNA and finally DNA synthesis, with the chemistry of DNA molecules receiving significant attention.

BB 550. Recombinant DNA Biochemistry

This course presents both theory and laboratory experience in recombinant DNA methodology. Topics covered include enzymology of DNA manipulation; construction and isolation of recombinants; plasmid and bacteriophage vectors; structural analysis of cloned DNA.

BB 560. Methods of Protein Purification and Downstream Processing

This course provides a detailed hands-on survey of state-of-the-art methods employed by the biotechnology industry for the purification of products, proteins in particular, from fermentation processes. Focus is on methods which offer the best potential for scale-up. Included are the theory of the design as well as the operation of these methods both at the laboratory scale as well as scaled up. It is intended for biology, biotechnology, chemical engineering, and biochemistry students. (Prerequisite: A knowledge of basic biochemistry is assumed.)

BB 565. Virology

This advanced-level course uses a seminar format based on research articles to discuss current topics related to the molecular/cell biology of viral structure, function, and evolution. Particular emphasis is placed on pathological mechanisms of various human disorders, especially emerging disease, and the use of viruses in research.

BB 570. Special Topics

Specialty subjects are offered using the research expertise of the department faculty. Content and format varies to suit the interest and needs of the faculty and students. This course may be repeated for different topics covered. Examples of topics given under this designation are:

Advanced Topics in Plant Physiology - P. Weathers

Grantsmanship - P. Weathers

Microbial Physiology - J. Miller

Education Seminar - J. Miller

Computer Applications in Nucleic Acids - D. Adams

Developmental Genetics - S. Politz

Immunology: Antibody Theory and Application - J. Rulfs

Animal Cell Culture as a Model System - J. Rulfs

Topics in Plant Cell Culture- R. Cheetham

Computational Methods for Biotechnology - T. Crusberg and faculty

Techniques in Polymerase Chain Reaction - D. Adams

Membrane Receptors - D. Gibson

Comparative Animal Physiology - D. Gibson

BB 580. Neurobiology

An introduction to neurobiology, with emphasis on the cellular and molecular basis of neural development and function. Topics will range from electrical and biochemical signaling between neurons, to higher order functions of the nervous system, such as sensation, movement, and memory. Human neurological diseases and disorders will be discussed. Includes reading of original papers from the scientific literature, and a presentation on a selected research topic.

BB 598. Directed Research

BB 599. Master's Thesis

BB 699. Ph.D. Dissertation

BIOMEDICAL ENGINEERING

BE 523. Biomedical Instrumentation

Origins and characteristics of bioelectric signals, recording electrodes, amplifiers, chemical pressure and flow transducers, noninvasive monitoring techniques, and electrical safety. (Prerequisites: Circuits and electronics, control engineering or equivalent.)

BE 525. Microprocessor-Based Biomedical Instrumentation

This course provides hands-on laboratory experience with common biomedical transducers and instrumentation used in physiological and clinical evaluation. Lectures and laboratory experiments cover electronic circuit design and construction, analog/digital signal acquisition and processing, and microprocessor-based biomedical instrumentation. The basic principles of hardware and software designs for interfacing biomedical sensors to a general purpose IBM-PC are emphasized. (Prerequisite: Analog and digital electronics.)

BE 541. Biological Systems

Review of control theory with applications to biological control systems. Theory and operation of analog and hybrid computers. Development of mathematical models of selected biological control systems and the application of computer techniques in the simulation of these systems. Course may be offered by special arrangement.

BE/ME 550. Tissue Engineering

This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include: material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented. (Recommended preparation: A first course in biomaterials equivalent to BE/ME 4814 and a basic understanding of physiology and cell biology.)

BE 551. Biological Signal Processing

Basic principles of digital processing of biological signals, and its application on PC-compatible computers. The theoretical fundamentals and practical examples of signal processing. The major emphasis is on linking the theoretical knowledge with easy to comprehend practical examples. (Prerequisite: Basic signal analysis.)

BE/ME 552. Tissue Mechanics

This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues and their relationship to physiological processes. Applications include: tissue injury, wound healing, the effect of pathological conditions upon tissue properties and design of medical devices and prostheses. (Recommended preparation: A first course in biomechanics equivalent to BE/ME 4504.)

BE/ME 554. Composites with Biomedical and Materials Applications

Introduction to fiber/particulate reinforced, engineered and biologic materials. This course focuses on the elastic description and application of materials that are made up of a combination of submaterials, i.e. composites. Emphasis will be placed on the development of constitutive equations that define the mechanical behavior of a number of applications, including: biomaterial, tissue, and materials science. (Prerequisites: understanding of stress analysis and basic continuum mechanics)

BE/ME 558. Biofluids and Biotransport

The emphasis of this course is on modeling fluid flow within the cardiovascular and pulmonary systems and the transport processes that take place in these systems. Applications include artificial heart valves, atherosclerosis, arterial impedance matching, clinical diagnosis, respiration, aerosol and particle deposition. Depending upon class interest, additional topics may include: reproductive fluids, animal propulsion in air and water and viscoelastic testing. (Recommended preparation: A first course in biofluids equivalent to BE/ME 4606.)

BE 560. Physiology for Engineers

An introduction to fundamental principles in cell biology and physiology designed to provide the necessary background for advanced work in biomedical engineering. Quantitative methods of engineering and the physical sciences are stressed. Topics include cell biology, DNA technology, and the physiology of major organ systems.

BE 562. Laboratory Animal Surgery

A study of anesthesia, surgical techniques, and postoperative care in small laboratory animals. Anatomy and physiology of species used included as needed. Class limited to 15 students. Approximately 15 surgical exercises are performed by each student.

BE 570. Engineering in the Clinical Environment

Examines the responsibilities and functions of the biomedical engineer in the health care complex in the solution of the technical and engineering problems associated with patient care. Topics include equipment management, monitoring systems, electrical safety, prosthetics, technical education for medical personnel, hospital systems engineering, and administrative functions.

BE 581. Medical Imaging Systems

Overview of the physics of medical image analysis. Topics covered include X-Ray tubes, fluoroscopic screens, image intensifiers; nuclear medicine; ultrasound; computer tomography; nuclear magnetic resonance imaging. Image quality of each modality is described mathematically, using linear systems theory (Fourier transforms, convolutions). (Prerequisite: Signal analysis course EE 3303 or equivalent.)

BE 582. Principles of In Vivo Nuclear Magnetic Resonance Imaging

This course emphasizes the applications of Fourier transform nuclear magnetic resonance (FTNMR) imaging and spectroscopy in medicine and biology. Course topics include: review of the basic physical concepts of NMR (including the Bloch equations), theoretical and experimental aspects of FTNMR, theory of relaxation and relaxation mechanisms in FTNMR instrumentation for FTNMR, NMR imaging techniques (point, line, plane, and volume methods), and in vivo NMR spectroscopy (including volume localization techniques). (Prerequisites: Differential and integral calculus, ordinary differential equations; organic chemistry recommended.)

BE 585. Principles of In Vivo Nuclear Magnetic Resonance Spectroscopy

This course emphasizes the applications of Fourier transform nuclear magnetic resonance (FTNMR) spectroscopy in medicine and biology. Course topics include: Review of the basic physical concepts of NMR, review of covalent chemical binding and its relationship to the NMR chemical shift, factors in biological systems that influence the NMR chemical shift, data acquisition and processing techniques in vivo NMR spectroscopy, and the application of NMR spectroscopy to clinical studies. (Prerequisites: BE 582, organic chemistry and biochemistry are strongly recommended.)

BE 591. Graduate Seminar

Topics in Biomedical Engineering are presented both by authorities in the field and full-time graduate students in the program. Provides a forum for the communication of current research and an opportunity for graduate students to prepare and deliver oral presentations. This is a required course (every semester) for all full-time graduate students (Prerequisite: graduate standing).

BE 595. Special Topics in Biomedical Engineering

Topics in Biomedical Engineering. Presentations and discussions of the current literature in one or more of the following areas: medical imaging, neurosensory systems, bio-statics.

BE 595M. Medical Device Regulation

This course provides an overview of regulations that guide the Medical Devices industry. Primary focus is on the Food, Drug and Cosmetic Act and its associated regulations. The course covers the FD&C Act, including definitions, prohibited acts, penalties and general authority. The course also covers regulations, including establishment registration, premarket approval (PMA), and current good manufacturing practices. Requirements of other federal agencies (NRC, FCC, EPA) will also be discussed.

BE 596. Research Seminar

Presentations on current biomedical engineering research.

BE 598. Directed Research

BE 599. Master's Thesis

BE 698 - Laboratory Rotation in Biomedical Engineering

Offered fall, spring, and summer for 3 or 4 credits (Prerequisite: PhD student in Biomedical Engineering).

BE 699. Ph.D. Dissertation

The following graduate/undergraduate biomedical engineering courses are also available for graduate credit.

BE/ME 4504. Biomechanics

This course emphasizes the applications of mechanics to describe the material properties of living tissues. It is concerned with the description and measurements of these properties as related to their physiological functions. Emphasis on the interrelationship between biomechanics and physiology in medicine, surgery, body injury and prosthesis. Topics covered include: Review of basic mechanics, stress, strain, constitutive equations and the field equations encountered in fluids, viscoelastic behavior and models of material behavior. The measurement and characterization of properties of tendons, skin, muscles and bone. Biomechanics as related to body injury and the design of prosthetic devices. (Prerequisites: Differential and integral calculus, ordinary differential equations, familiarity with the concepts of mechanics.)

BE/ME 4606. Biofluids

This course emphasizes the applications of fluid mechanics to biological problems. The course concentrates primarily on the human circulatory and respiratory systems. Topics covered include: blood flow in the heart, arteries, veins and microcirculation and air flow in the lungs and airways. Mass transfer across the walls of these systems is also presented. (Prerequisite: A background in continuum mechanics (ME 2504) and fluid mechanics equivalent to ME 3602 is assumed.)

BE/ME 4814. Biomedical Materials

This course discusses various aspects pertaining to the selection, processing, testing (in vitro and in vivo) and performance of biomedical materials. The biocompatibility and surgical applicability of metallic, polymeric and ceramic implants and prosthetic devices are discussed. The physico-chemical interactions between the implant material and the physiological environment will be described. The use of biomaterials in maxillofacial, orthopedic, dental, ophthalmic and neuromuscular applications is presented.(Prerequisite: Knowledge of introductory materials science (ES 2001) is assumed.)

The following courses in the Graduate School of Biomedical Sciences (GSBS) at the University of Massachusetts, Worcester (UMW) are appropriate for students in the Biomedical Engineering program and are available for graduate credit. While these are the most common courses taken by our students, many other GSBS courses not listed in this catalog may also be available for graduate credit.

Biomedical Science Core (I and II)
Provides students with an integral foundation in the sciences basic to medicine, emphasizing contemporary topics in biological chemistry, transfer of genetic information, cellular architecture and regulation, and multi-cellular systems and processes. Students may take all or part of the core, in either quarter or semester format.

Biomedical Sciences I (6 credits)

Quarter I: Biochemistry (3 credits)

Quarter II: Molecular Biology and Genetics (3 credits)

Biomedical Sciences II (6 credits)

Quarter III: Cell Biology (3 credits)

Quarter IV: Systems (3 credits).

Responsible Conduct of Science
Ethics course on the responsible conduct of science (1 credit).

PY700 "The Cell Works": Principles of Cell Physiology

The objectives of "The Cell Works" are to provide a fundamental understanding of: (1) the basic biophysical principles of cell physiology, (2) the ability to relate cellular function to whole organ physiology and (3) the cellular mechanisms underlying disease. By emphasizing the principles of cell physiology, the course will identify important physiological paradigms and the modern research methods used to resolve outstanding questions concerning cell function. (Prerequisites: Biochemistry and Molecular Biology) (4 credits)

PY740 "The Image Works": Optical Methods in Physiology

This course studies basic optical techniques and their application to physiological problems, with special emphasis on digital image processing. (Prerequisites: Calculus) (2 credits)

PY750 "The Body Works": Cellular and Organ Physiology

The objectives of "The Body Works" are to provide a fundamental understanding of: (1) the basic biophysical principles of physiology, (2) the relationship between cellular function and whole organ physiology, (3) the integration and regulation of the major organ systems of the human body and (4) the mechanism of pathogenesis of disease. By correlating cellular processes with organ function, this course will identify important physiological paradigms and the modern research methods used to resolve outstanding questions. (Prerequisites: Biochemistry, Molecular Biology, and Cell Physiology) (3 credits)

CHEMICAL ENGINEERING

CM 501-502. Seminar

Reports on current advances in the various branches of chemical engineering or on graduate research in progress. Must be taken during every semester in residence.

*CM 504. Mathematical Analysis in Chemical Engineering

Methods of mathematical analysis selected from such topics as vector analysis, matrices, complex variables, eigenvalue problems, Fourier analysis, Fourier transforms, Laplace transformation, solution of ordinary and partial differential equations, integral equations, calculus of variation, and numerical analysis. Emphasis on application to the solution of Chemical Engineering problems.

*CM 506. Kinetics and Catalysis

Theories of reaction kinetics and heterogeneous catalysis for simple and complex reactions. Kinetics and mechanisms of catalyzed and uncatalyzed reactions, and effects of bulk and pore diffusion. Techniques for experimentation, reaction data treatment, and catalyst preparation and characterization.

*CM 507. Chemical Reactor Design

Includes a review of batch, tubular, and stirred tank reactor design. Kinetics review: including advanced chemical kinetics and biochemical kinetics; transport processes in heterogeneous reactions. In-depth reactor analysis includes: fixed bed reactors, multiplicity and stability of steady states, reactor dynamics, optimal operation and control, biological reactors, nonideal flow patterns, and fluidized bed and multiphase reactors.

CM 508. Catalysis and Surface Science of Materials

Examines detailed structures and reactivities of solid catalysts: zeolites, solid state inorganics, supported metals and metal-support interactions, carbon catalysts, anchored catalysts and others. Important analytical techniques covered include: X-ray photoelectron spectroscopy (ESCA), electron microprobe, AUGER, scanning electron microscopy, EXAFS, Mossbauer, Fourier-transform infrared, enhanced laser Raman spectroscopy and photoacoustics spectroscopy. Examines relationship between structures and reactivities of important catalysts in hydrocarbon oxidation and functionalization, syngas reactions, and petroleum processing.

CM 510. Dynamics of Particulate Systems

Analyzes discrete particles which grow in size or in some other characteristic variable (e.g., age, molecular weight, etc.). Reaction engineering and population balance analyses for batch and continuous systems. Steady state and transient system dynamics. Topics may include: crystallization, latex synthesis, polymer molecular weight distribution, fermentation/ecological systems, and gas-solid systems.

CM 521. Biochemical Engineering

Ligand binding and membrane transport processes; growth kinetics of animal cells and micro-organisms; kinetics of interacting multiple populations; biological reactor design and analysis; soluble immobilized enzyme kinetics; and optimization and control of fermentation; biopolymer structure and function; properties of biological molecules; biological separation processes; scale-up of bioprocesses; laboratory work may be included when possible.

CM 543. Molecular Sieves

The structure, synthesis and properties of micro-porous crystals known as zeolites are examined. Major topics are systemization of crystal structures, zeolite syntheses and their mechanisms, spectroscopic characterization, physical properties, and catalytic properties.

*CM 561. Advanced Thermodynamics

Examination of the fundamental concepts of classical thermodynamics and presentation of existence theorems for thermodynamics properties. Inequality of Clausius as a criterion for equilibrium in both chemical and physical systems. Examination of thermodynamic equilibrium for a variety of restraining conditions. Applications to fluid mechanics, process systems, and chemical systems. Computation of complex equilibria.

+ *CM 571. Intermediate Transport Phenomena

Mass, momentum and energy transport; analytic and approximate solutions of the equations of change. Special flow problems such as creeping, potential and laminar boundary-layer flows. Heat and mass transfer in multi-component systems. Estimation of heat and mass transfer rates. Transport with chemical reaction.

+ *CM 572. Mass and Energy Transfer

Advanced treatment of heat and mass transfer. Topics from: forced and natural convection; high-speed and rarefied gas flows; film and dropwise condensation, spray cooling, boiling and two-phase flow; packed and fluidized bed heat and mass transfer; the heat pipe; radiant transfer within enclosures, including radiation from gases and flames; ionic transport and electrochemical systems; combustion and mass transfer; drying and diffusion in porous materials, mass transfer in living systems; turbulent mass transfer; adsorption; design of heat and mass transfer equipment. Course may be offered by special arrangement.

*CM 573. Separation Processes

Thermodynamics of equilibrium separation processes such as distillation, absorption, adsorption and extraction. Multi-staged separations. Principles and processes of some of the less common separations.

*CM 574. Fluid Mechanics

Advanced treatment of fluid kinematics and dynamics. Stress and strain rate analysis using vectors and tensors as tools. Incompressible and compressible, one-dimensional flows in channels, ducts and nozzles. Nonviscous and viscous flow fields. Boundary layers and turbulence. Flow through porous media such as fixed and fluidized beds. Two-phase flows with drops, bubbles and/or boiling. Introduction to non-Newtonian flows.

CM 580. Transformation and Transport in the Environment

This course will focus on the transformation and transport of pollutant chemicals, nutrients and colloids in natural and engineered environmental systems. The first part of the course deals with the transfer of chemicals between different environments (water and air, water and solid phases). The second part of the course deals with processes by which a compound is chemically or biologically transformed into one or more products.
Research - as arranged

CM 594 (FPE 574). Process Safety Management

This course provides basic skills in state-of-the-art process safety management and hazard analysis techniques including Hazard and Operability Studies (HAZOP), Logic Trees, Failure Modes and Effects Analysis (FMEA) and Consequence Analysis. Both qualitative and quantitative evaluation methods will be utilized. Following a case study format, these techniques along with current regulatory requirements will be applied through class projects addressing environmental health, industrial hygiene, hazardous materials, fire or explosion hazard scenarios. (Prerequisite: An undergraduate engineering or physical science background.)

+ Only 1 (one) course for core credit

***** Core Chemical Engineering Courses

CHEMISTRY & BIOCHEMISTRY

CH 501. Chemistry of the Main Group Elements

An advanced course in recent developments in selected areas of the chemistry of the elements other than transition metals. Topics covered may include electron deficient compounds and main group organometallics; the preparation, reactions and physical properties of these compounds. Course may be offered by special arrangement.

CH 502. Bioinorganic Chemistry

The subject matter of this course is bioinorganic chemistry, with emphasis on the application of physical methods to the study of active sites in bioinorganic systems. The physical methods discussed include magnetic susceptibility measurements, electronic absorption spectroscopy, resonance Raman spectroscopy, electron spin resonance, EXAFS, and electrochemical techniques. Applications of these to a variety of metalloproteins, including oxygen carriers (myoglobin, hemoglobin, hemocyanin), blue copper proteins, iron sulfur proteins, and low molecular weight structural and functional model systems are covered in detail.

CH 516. Chemical Spectroscopy

Advanced topics in identification of molecular species and determination of molecular structure by spectroscopic methods.

CH 531. Electronic Interpretation of Organic Reactions

Organic reaction mechanisms are interpreted in terms of "electron-pushing" rationalizations and elementary molecular orbital theory. The course involves a series of problem-solving discussion sessions.

CH 533. Physical Organic Chemistry

Mechanisms of representative organic reactions, and the methods used for their evaluation. Structural, electronic, and stereochemical influences on reaction mechanisms.

CH 534. Organic Photochemistry

Introduction to the photophysical and photochemical consequences of light absorption by molecules. Experimental techniques, excited state description, photochemical kinetics and energy transfer are among the topics discussed in relation to the primary photochemical reactions in simple and complex molecules.

CH 536. Theory and Applications of NMR Spectroscopy

This course emphasizes the fundamental aspects of 1D and 2D nuclear magnetic resonance spectroscopy (NMR). The theory of pulsed Fourier transform NMR is presented through the use of vector diagrams. A conceptual non mathematical approach is employed in discussion of NMR theory. The course is geared toward an audience which seeks an understanding of NMR theory and an appreciation of the practical applications of NMR in chemical analysis. Students are exposed to hands on NMR operation. Detailed instructions are provided and each student is expected to carry out his or her own NMR experiments on a Bruker AC-200 instrument.

CH 537. Natural Products

The course will provide a review of the chemistry and synthesis of compounds from representative families of products such as terpenoids, steroids, polyketides, alkaloids, and B-lactams. Prospective students should have a good foundation in organic chemistry.

CH 538. Medicinal Chemistry

This course will focus on the medicinal chemistry aspects of drug discovery from an industrial pharmaceutical research and development perspective. Topics will include Chemotherapeutic Agents (such as antibacterial, antiviral and antitumor agents) and Pharmacodynamic Agents (such as antihypertensive, antiallergic, antiulcer and CNS agents). (Prerequisite: A good foundation in organic chemistry e.g., CH 2310 Organic Chemistry I and CH 2320 Organic Chemistry II.)

CH 539. Molecular Pharmacology

After a review of the pertinent aspects of human physiology, the course will focus on the variety of chemical messengers in the body, their storage release, action on target receptors, and eventual fate. Discussion of endocrine receptors introduces the fundamental concepts of receptor-effector coupling which are developed further in studies of the molecular structure and function of ion channels with application to the nerve impluse, and of the acetylcholine receptors. Concepts of agonist and antagonist specificity, nonspecific blocking, drug addiction, etc. will be further developed in discussions of the cathecholamines, and the neuractive peptides. Nonreceptor blocking will be further developed in a segment of ion cotransport systems in renal regulation.

A knowledge of the material covered in one of the following is recommended: (a) CH 4110 and CH 4120, or (b) BB 3100, or (c) CH 538 plus an understanding of protein and membrane structures.

CH 552. Statistical Mechanics

Application of the results of the quantum theory to achieve an atomistic physical understanding of the common thermodynamic variables. Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein distribution functions are defined using the concepts of phase space and the exclusion principle, and the thermodynamic functions are developed in terms of the distribution functions. Application of the partition function and the theory of fluctuations to common physical systems. Course may be offered by special arrangement.

CH 553. Quantum Mechanics of Molecules

Time dependent perturbation theory and the absorption of radiation by matter. Separation of electronic and nuclear motions in molecules. The quantum mechanical description of the covalent bond and directed valence. The valence bond and molecular orbital models of the electronic structure of complex molecules. Group theory and the vibrations of polyatomic molecules. Course may be offered by special arrangement.

CH 554. Molecular Modeling

This course trains students in the area of molecular modeling using a variety of quantum mechanical and force field methods. The approach will be towards practical chemists who want to answer specific questions about molecular geometry, transition states, reaction paths, and photoexcited states. No experience in programming is necessary; however, a background at the introductory level in quantum mechanics is highly desirable. Methods to be explored include Extended Huckel Theory, Molecular Mechanics, Semiempirical Molecular Orbital Methods, Ab initio Methods, Graphical Display of Molecules.

CH 555. Advanced Topics

1- 3 credits as arranged

A course of advanced study in selected areas whose content and format varies to suit the interest and needs of faculty and students. This course may be repeated for different topics covered.

CH 556. Experimental Photochemistry

This course illustrates how modern spectroscopic techniques can be used to learn more about the photo-induced chemistry of organic materials. The principles of time-resolved and steady-state spectroscopic methods will be described in lectures and then applied in the laboratory to a variety of chemical systems. The aim will be to show how it is possible to fully describe the ground and excited state photochemical behavior of a chemical system using these techniques. Aspects of uv-visible fluorescence emission; phosphorescence emission; and laser-flash photolysis will be discussed. Students will gain hands-on experience with the use of UV-visible absorption and fluorescence emission spectrometers as well as the laser flash photolysis research facility. Also, as part of the course, students will submit a short research proposal based on one or more of the techniques used. Although there is no formal requirement for this course, some background and an interest in photochemisty would be an asset.

CH 560 Current Topics in Biochemistry

1 credit per semester

CH 571. Seminar

0.5 credit per semester

Reports on current advances in the various branches of chemistry.

The following graduate/undergraduate chemistry courses are also available for graduate credit.

CH 4110. Biochemistry I

Cell organization and the physical and chemical properties of biomolecules including amino acids, peptides, proteins, carbohydrates and lipids are discussed. Biochemical dynamics is introduced through a study of enzymes, coenzymes, and enzyme kinetics. Bioenergetics, the role of ATP, its production through glycolysis, and the tricarboxylic acid cycle are discussed in detail.

CH 4120. Biochemistry II

Oriented around biological membranes, this term begins with a discussion of electron transport and the aerobic production of ATP followed by a study of photosynthesis. The study of the biosynthesis of lipids and steroids leads to a discussion of the structure and function of biological membranes. Finally, the membrane processes in neurotransmission are discussed.

CH 4130/BB 4910. Biochemistry III/ Molecular Biology

Synthesis of biologically important macromolecules is the chief topic of this course. Selected readings from the scientific literature are used to illustrate the milestones of molecular biology and the development of techniques and experiments. Protein synthesis and ribosome structure lead into a discussion of mRNA and finally DNA synthesis, with the chemistry of recombinant DNA molecules receiving significant attention. (Prerequisite: A knowledge of basic principles of organic chemistry, elementary theromodynamics and introductory biology including knowledge of cellular components and their biochemical and physiological functions is assumed.)

CH 4190. Regulation of Gene Expression

This course will cover the biochemical mechanisms involved in regulation of gene expression: modifications of DNA structures that influence transcription rates, transcriptional regulation by protein binding, post-transcriptional modification of RNA including splicing and editing, regulation of translation including ribosome binding and initiation of translation, and factors that control the half-lives of both mRNA and protein. During the course, common experimental methods will be explored, including a discussion of the information available from each method.

Recommended background: CH 4110, CH 4120, CH 4130, BB 4010.

CH 4330. Organic Synthesis

A discussion of selected modern synthetic methods including additions, condensations, and cyclizations. Emphasis is placed on the logic and strategy of organic synthesis. (Prerequisite: Competence in elementary organic synthesis is assumed.)

CH 4420. Inorganic Chemistry II

This course deals with the stereochemistry of and the bonding in transition metal complexes of both the classical and organometallic types. The crystal field and molecular orbital theories of bonding in such complexes are treated in detail. Special attention is given to reactions and catalysts.

CH 4520. Chemical Statistical Mechanics

This course provides an introduction to the statistical methods of determining thermodynamic properties of substances from basic information about the atomic and molecular units from which they are formed. Through calculation of thermodynamic quantities and the evaluation of chemical equilibrium constants, broad insights into the kinetic molecular theory and the significance of the concepts of entropy and energy are developed.

CH 4550. Polymer Chemistry

Fundamentals of polymer science and technology based on organic polymers. The principal mechanisms of polymerization including radical, ionic and condensation, are covered in detail. Characterization of polymers by physical means. Mechanical behavior including bulk and solution properties of polymers. Polymer syntheses and modifications including graft and copolymerization. Structure, property and end use applications of plastic materials. Plastics processing, testing and technology. Survey of commodity plastics as well as engineering resins including their applications and economic considerations. Presentation of trade and technical literature in the field.

CIVIL & ENVIRONMENTAL ENGINEERING

CE 501. Professional Practice

Professional practices in engineering. Legal issues of business organizations, contracts, and liability; business practice of staffing, fee structures, accounts receivable, negotiation and dispute resolution, loss prevention; marketing and proposal development; project management involving organizing and staffing, budgeting, scheduling, performance and monitoring, and presentation of deliverables; professionalism, ethics, and responsibilities.

CE 510. Structural Mechanics

Analysis of structural components: Uniform and non-uniform torsion of structural shapes; analysis of determinate and indeterminate beams (including elastic foundation conditions) by classical methods; finite difference equations; numerical integrations; series approximation; elastic stability of beams and frames; lateral stability of beams; beams-columns; analysis of frames including the effect of axial compression. Course may be offered by special arrangement.

CE 511. Structural Dynamics

Analysis and design of beams and frames under dynamic loads; dynamics of continuous beams, multi-story building frames, floor systems and bridges; dynamic analysis and design of structures subjected to wind and earthquake loads; approximate methods of analysis and practical design applications.

CE 512. Structural Stability Theory

Theory of elastic and inelastic buckling of beam columns and frames; lateral and torsional buckling of beams; buckling rings, arches and thin plates; buckling of shells; design equations and finite element methods in stability; bending of thin plates and shells. Use of Microcomputers in stability problems. Course may be offered by special arrangement. (Prerequisite: Differential equations, structural mechanics and matrix structural analysis will be assumed.)

CE 519. Advanced Structural Analysis

Energy methods in structural analysis; concepts of force method and displacement methods; methods of relaxation and numerical techniques for the solution of problems in buildings; longspan structures and aircraft structural systems. Effects of secondary stress in structures. Course may be offered by special arrangement. (Prerequisites: Structural mechanics and undergraduate courses in structural analysis, differential equations.)

CE 523. Advanced Matrix Analysis

Review of Matrix Computer Methods of Structural Analysis including the stiffness and flexibility methods, energy formulation, Eigenvalue problems, the finite element method, elements suitable for analysis, structural dynamic problems, computer solutions of numerous examples using time-sharing programs and STRUDL.

CE 524. Stress Analysis by Finite Elements

(Same as ME 533) See course description under ME 533 on page 89.

CE 525. Analysis and Design of Shell Structures

Analysis and design of thin shell concrete structures such as domes, cylindrical shells, hyperbolic paraboloids, shells of double curvature and folded plate roof systems; membrane theory of thin shells and the methods of analysis for displacements and stress-resultants; methods of analysis of shells including finite element formulations; design of cylindrical, spherical and hypar shell structures; applications to long span roof systems, arch dams and liquid- containment structures. An understanding of the undergraduate topics in structural mechanics, reinforced concrete design and differential equations is assumed.

CE 526. Advanced Finite Element Methods

(Same as ME 633) See course description under ME 633 on page 90.

CE 531. Advanced Design of Steel Structures

Advanced design of steel members and connections; ultimate strength design in structural steel; codes and specifications; loads and working stresses; economic proportions; buckling of slender elements and built-up sections, torsion, lateral-torsional buckling, beam-columns, design for lateral forces, and connections for building frames.

CE 532. Advanced Design of Reinforced Concrete Structures

Advanced design of reinforced concrete members and structural systems; effect of continuity; codes and specifications; ultimate strength theory of design; economic proportions and constructibility considerations; deep beams, torsion, beam-columns, two-way slabs, design for lateral forces, and beam-to-column joints.

CE 533. Prestressed Concrete Structures

Analysis and design of prestressed concrete structures. Linear prestressing; materials used in prestressed concrete; determinate and statically indeterminate prestressed concrete structures; connections; shear and torsion. Design of tension and compression members and flat plates. (Prerequisite: A knowledge of undergraduate course in concrete design is necessary.)

CE 534. Structural Design for Fire Conditions

The development of structural analysis and design methods for steel and reinforced concrete members subjected to elevated temperatures caused by building fires. Beams, columns and rigid frames will be covered. The course is based on research conducted during the past three decades in Europe, Canada and the U.S. Course may be offered by special arrangement. (Prerequisites: Knowledge of statically indeterminate structural analysis, structural steel design and reinforced concrete design.)

CE 535. Integration of Design and Construction

As an interactive case study of the project development process, student groups design a facility and prepare a construction plan, including cost and schedule, to build the project. The students present their design-build proposal to participating industrial clients. Emphasis is on developing skills to generate, evaluate and select design alternatives that satisfy the needs of the owner and the constraints imposed by codes and regulation as well as by the availability of construction resources. Emphasis is also in developing team-building skills and efficient communication. Computer-based methods for design, construction cost estimating and scheduling, and personal communications are extensively used. The interactive case study is specifically chosen to balance the content between design, construction engineering, and management. Students taking this course are expected to have a background in at least two of these disciplines.

CE 536. Construction Failures: Analysis and Lessons

This course develops an understanding of the integration process of technical, human, capital, social, and institutional aspects that drive the life cycle of a construction project. The study of failures provides an excellent vehicle to find ways for the improvement of planning, design and construction of facilities. Student groups are required to complete a term project on the investigation of a failure and present their findings and recommendations. This investigation includes not only the technical analysis of the failure but also requires a comprehensive analysis of the organizational, contractual, regulatory aspects of the process that leads to the failure. The course uses case studies to illustrate different types of failure in the planning, design, construction, and operation of constructed facilities. Students taking this course are expected to have some background in the disciplines mentioned above.

CE 537. Advanced Properties and Production of Structural Materials

This course is particularly designed for Civil Engineers and will cover structure, properties and performance of construction materials. Topics include the structure of solids, phase equilibrium and reaction kinetics.

A detailed analysis of mechanical properties and deterioration of solids will be presented. Theories and mathematical models based on these concepts will be applied to construction materials such as cementitious materials, bituminous materials, metals and alloys, timber, ceramics and composites. (Prerequisites: Structural mechanics, materials of construction, differential equations and computer literacy.)

CE 538. Pavement Analysis and Design for Highways and Airports

This course is designed for civil engineers and will provide a detailed survey of analysis and design concepts for flexible and rigid pavements for highways and airports. The materials will cover elastic and inelastic theories of stress pavement components, and currently used design methods, i.e., Corp of Engineers, AASHTO, etc. The use of finite element methods for pavement stress and deformation analysis will be presented. A review of pavement rehabilitation methods and processes will be presented. (Prerequisites: Differential equations, construction materials, soil mechanics, computer literacy.)

CE 542. Geohydrology

This course addresses engineering problems associated with the migration and use of subsurface water. An emphasis is placed on the geology of water-bearing formations including the study of pertinent physical and chemical characteristics of soil and rock aquifers. Topics include principles of groundwater movement, geology of groundwater occurrence, regional groundwater flow, water well technologies, construction dewatering, groundwater chemistry, and unsaturated flow. (Prerequisite: A knowledge of the material in GE 2341 is recommended.)

CE 550. Theoretical Soil Mechanics

This course provides an advanced level study of theories of soil behavior and mechanics. The topics reviewed are physico-chemical factors affecting soil behavior, the effective stress principle, moisture migration, application of the theory of elasticity to compute stresses in soil masses, settlement analysis, consolidation theory and geothermics. Appropriate laboratory and field testing procedures are discussed. Course may be offered by special arrangement.

CE 551. Theoretical Soil Mechanics II

A continuation of CE 550. It addresses the nature of the strength-deformation characteristics of both rapidly and slowly draining soils. Stress path methods of analysis and critical state behavior models are emphasized. Elastic and plastic material failure theories are reviewed and modern laboratory and field testing devices are described. Course may be offered by special arrangement.

CE 552. Earth Structures

This course provides an in-depth study of the geotechnical principles applied to design of earth structures including earth dams, waste containment facilities, soil slopes, highway cuts, embankments, and slurry trenches. It includes fundamentals of analysis of flow through porous media by graphical and digital techniques, slope stability, use of geosynthetics, soil stabilization and the design of preloads and drain installation. Course may be offered by special arrangement.

CE 553. Advanced Foundation Engineering

This course covers advanced methods of subsurface exploration and recent developments in prediction of bearing capacity and settlement of shallow foundations. It includes design of mat foundations, analysis and design of pile and drilled shaft foundations, and discussion of case studies. The course content is determined in part by the student's interests and often also includes design of lateral support systems, reinforced earth, de watering systems and buried structures.

CE 560. Advanced Principles of Water Treatment

Theory and practice of water treatment. Aeration, water softening, coagulation sedimentation, water infiltration, disinfection, taste and odor control, desalination and corrosion control.

CE 561. Advanced Principles of Waste Water Treatment

Theory and practice of waste water treatment. Natural purification of streams, screening, sedimentation, flotation, thickening, aerobic treatment methods, theory of aeration, an-aerobic digestion, disposal methods of sludge including vacuum filtration, centrifugation, and drying beds, wet oxidation, removal of phosphate and nitrogen compounds, and tertiary treatment methods.

CE 562. Biosystems in Environmental Engineering

Application of microbial and biochemical understanding to river and lake pollution, natural purification processes, biological conversion of important elements such as C, N, S, O and P, biological aspects of waste water treatment, disease producing organisms with emphasis on waterborne diseases, quantitative methods used in indicator organism counts and disinfection.

CE 5621. Open Channel Hydraulics

This course begins with fundamentals of free surface flow and includes engineering and environmental applications. Development of basic principles, including specific energy, momentum and critical flow. Rapidly varied, uniform and gradually varied steady flow phenomena and analysis. Density stratified flow. Similitude considerations for hydraulic models. Optional topics; dispersion and heat transfer to atmosphere. Course may be offered by special arrangement. (Prerequisite: Fluid mechanics or permission of department head.)

CE 563. Industrial Waste Treatment

Legislation, the magnitude of industrial wastes, effects on streams, sewers and treatment units, physical, chemical and biological characteristics, pre-treatment methods, physical treatment methods, chemical treatment methods; biological treatment methods, and wastes from specific industries. Lab includes characterization and treatment of typical industrial wastes.

CE 564. Solid Waste Management

Sources and types of solid wastes; generation rates; environmental, public health and aesthetic aspects, on-site handling, storage and processing, collection systems, transfer and transport of solid wastes; processing techniques and equipment, recovery of resources and energy; composting; disposal methods of solid wastes and residual matter; hazardous wastes handling; solid waste legislation and governmental agencies; solid waste management issues and options; case studies.

CE 565. Stream, Lake and Estuarine Analysis

This course provides a quantitative base for determining the fate of effluent discharged into natural waters. Models are developed to describe the transport, dispersal, and chemical/biological reaction of substances introduced in rivers, estuaries, lakes and coastals areas. The concept of conservation of mass is used to derive the general transport equation. This equation is applied to analyze BOD, DO, temperature, nutrients and plankton population dynamics. Other topics include salinity intrusion in estuaries, thermal stratification of reservoirs is on physio-biological predictions as a tool for water quality management.

CE 566. Groundwater Flow and Pollution

This course provides a review of the basic principles governing ground water flow and solute transport and examines the models available for prediction and analysis, including computer models. Topics covered include: mechanics of flow in porous media, development of the equations of motion and of conservation of solute mass, analytical solutions, computer-based numerical approaches and application to seepage, well analysis, artificial recharge, groundwater pollution, salinity intrusion and regional groundwater analyses.

CE 567. Hazardous Waste: Containment, Treatment and Prevention

This course provides a survey of the areas associated with hazardous waste management. The course materials deal with identification of hazardous waste legislation, containment, storage, transport, treatment, and other hazardous wastes management issues. Topics include hazardous movement and containment strategies, barrier design considerations, hazardous waste risk assessment, spill response and clean up technologies, centralized treatment facilities, on-site treatment, in situ treatment, and industrial management and control measures. Design of selected containment and treatment systems, and a number of industrial case studies are also covered. This course is offered to students with varying backgrounds. Students interested in taking this course must identify a specific problem that deals with either regulation, containment of hazardous waste, treatment of hazardous waste or industrial source reduction of hazardous waste. This problem becomes the focal point for in-depth study. The arrangement of topics between the students and the instructor must be established by the third week. A knowledge of basic chemistry is assumed.

CE 568. Design of Water Distribution Piping Systems

This course covers both hydraulic and water quality modeling of water distribution systems. Emphasis is placed on potable water distribution systems for municipal use, but high purity water networks for industrial use is also covered. Popular software models currently used for this type of analysis, such as the KYPIPE, CYBERNET and EPANET models, are used.

CE 569. Environmental Engineering Treatability Laboratory

This course addresses an aspect of environmental engineering that has been unavailable to civil engineering students in the past. As modern methods of dealing with complex facilities to remediate pollution become more in demand, this course will become an important component of environmental education.

CE 570. Multiphase Contaminant Transport

Introduces concepts of physical transport processes in the environment with emphasis on exchanges across phase boundaries. Topics include equilibrium conditions of environmental interfaces, partitioning and distribution of contaminants in the environment, transport across sediment-water interfaces, dispersion, sorption, and the movement of non-aqueous phase liquids in groundwater, gas exchanges across air-water interfaces, effects of turbulence and particles on transport in surface water flow, and the effects of reactions on the transport in the environment. (Prerequisite: A knowledge of the material covered in ES 3004 and CE 3069 is expected.)

CE 580. Advanced Project Management

This course develops an understanding of the managerial principles and techniques used throughout a construction project as they are applied to its planning, preconstruction and construction phases. The course emphasizes the integrative challenges of the human, physical and capital resources as they are experienced from the owner's point of view in the preconstruction phase of a project. Through assignments and case studies, the course reviews the complex environment of construction industry and processes, project costing and economic evaluation, project organization, value engineering, time scheduling, contracting and risk allocation alternatives, contract administration, and cost and time control techniques.

CE 581. Real Estate Development

Principles of real estate development, emphasizing the system approach to process of conception, design, construction and operation; organization and control systems for real estate development, value and decision analysis.

CE 582. Engineering and Construction Information Systems

This course provides an understanding of the various subjects involved in the use, design, development, implementation, and maintenance of computer-based information systems in the construction industry. Theoretical and hands-on review of basic building blocks of information and decision support systems including user interfaces, database management systems, object-oriented approaches and multimedia. Applications include project scheduling and cost control, budgeting, project risk analysis, construction accounting, materials management and procurement systems, project document tracking, and resource management. Commercial software such as PRIMAVERA Project Planner, TIMBERLINE, spreadsheets and databases is extensively used. Students are required to complete a term project reviewing an existing information system and presenting recommendations for improvement. (Prerequisites: a knowledge of the material covered in CE 580, CE 584, and CE 585 is expected). Course may be offered by special arrangement.

CE 583. Contracts and Law for Civil Engineers

An introduction to the legal aspects of construction project management; emphasis on legal problems directly applied to the practice of project management; contracts and specifications documents; codes and zoning laws; labor laws.

CE 584. Advanced Cost Estimating Procedures

This course examines cost estimating as a key process in planning, designing and constructing buildings. Topics include the analysis of the elements of cost estimating; data base development and management, productivity, unit costs, quantity surveys and pricing and the application of these tools in business situations; marketing, sales, bidding, negotiating, value engineering, cost control, claims management and cost history. Computerization is evaluated as an enhancement to the process.

CE 585. Information Technology in the Integration of Civil Engineering

This course provides an understanding and hands-on experience of state-of-the-art information technology and its application to the planning, design, construction, and management of civil engineering projects. These technologies include integrated database management systems, electronic data interchange (EDI), electronic media for date input/output (bar coding, voice recognition, image processing), networks, and knowledge-based systems. The course format includes formal lectures, computer laboratory sessions, and a class project developed collaboratively by the students throughout the term. Using information technology, the class develops a package that includes drawings, specifications, cost estimate and schedule of a civil engineering project. (Prerequisites: Basic knowledge of computers and construction project management.)

CE 586. Building Systems

This course introduces design concepts, components, materials, and processes for major building projects. The topics analyze the choice of foundations, structures, building enclosures, and other major building subsystems as affected by environmental and legal conditions and market and project constraints. Consideration is given to the functional and physical interfaces among building subsystems. Emphasis is given to the processes through which design decisions are made in the evolution of a building project.

CE 590. Special Problems

2 to 4 credits

Individual investigations or studies of any phase of civil engineering as may be selected by the student and approved by the faculty member who supervises the work.

CE 591 Environmental Engineering Seminar

Participation of students in discussing topics of interest to environmental engineers.

CE 592. Constructed Facilities Seminar

Participation of students, faculty, and recognized experts outside of WPI in developing modern and advanced topics of interest in the constructed facilities area.

CE 593. Advanced Project

This capstone project is intended for students completing the M. Eng. degree. The student is expected to identify all aspects of the M. Eng. curriculum and an integrative, descriptive systems approach. The project activity requires the student to describe the development, design construction, maintenance, and operation process for an actual facility, to evaluate the performance of the facility with respect to functional and operational objectives, and to examine alternative solutions. Specific areas of study are selected by the student and approved by the faculty member. The work may be accomplished by individuals or small groups of students working on the same project. (Prerequisite: Consent of instructor.)

CE 599. M.S. Thesis

Research study at the M.S. level.

CE 699. Ph.D. Thesis

Research study at the Ph.D. level.

COMPUTER SCIENCE

CS 501. Discrete Structures

Topics from discrete mathematics relevant to computer science are presented in a way that helps the student develop a facility for dealing with abstractions and formal proofs. These topics include sets, relations, posets, graphs, digraphs, monoids, groups, discrete probability theory and propositional calculus. (Prerequisites: College math at least through calculus and some experience with recursive programming.) NOTE: This course is intended only for students with a limited formal computer science background and should only be taken with advisor or instructor approval.

CS 502. Operating Systems

The design and theory of multiprogrammed operating systems, concurrent processes, process communication, input/output supervisors, memory management, resource allocation and scheduling are studied. (Prerequisites: Knowledge of computer organization, elementary data structures and a strong programming background.)

CS 503. Foundations of Computer Science

The foundations of computer science are presented here. These form the basis for a more complete understanding of and proficiency in computer science. Topics include logic, computational models, formal languages, computability, and complexity theory. (Prerequisite: Undergraduate or graduate level discrete structures such as CS 2022, CS 501 or MA 2201.)

CS 504. Analysis of Computations and Systems

The following tools for the analysis of computer programs and systems are studied: probability, combinatorics, the solution of recurrence relations, and the establishment of asymptotic bounds. A number of algorithms and advanced data structures are discussed, as well as paradigms for algorithm design. (Prerequisites: The ability to write a structured program in a recursive language and a knowledge of discrete mathematics at the undergraduate level.)

CS 505. Social Implications of Computing

This course is concerned with the effects of computer technology on society. It will explore a wide range of topics, including privacy, liability, proprietary protection, the effects of artificial intelligence on humanity's view of itself, and globalization. It will also consider the issues of professional ethics and professional responsibility, as well as discrimination in the workplace, in education, and in user interfaces. Papers, presentations, discussions, extensive readings, and a course project are possible components of this course. (Prerequisites: A college degree and either two computer science classes or a year's experience in the computer industry including sales and management.)

CS 507. Data Structures and Analysis of Algorithms

This course studies different data structures from the point of view of the operations performed upon the data and to apply analysis and design techniques to non-numeric algorithms that act on data structures. Data structures are presented as abstract objects admitting certain operations. Choices of internal representations and algorithms to implement them are covered in some detail. The data structures covered include lists, stacks, queues, priority queues, trees, balanced trees, graphs and dictionaries. Projects and assignments will treat the development of theoretical results, the writing of programs to obtain practical results, and techniques to integrate different data structures in complex algorithms that place a variety of demands upon them. (Prerequisites: The student is expected to know a recursive programming language, to have taken two years of college math and an undergraduate course in data structures, and to have exposure to formal mathematics as might be found in CS 501.) NOTE: This course is intended only for students with a limited formal computer science background and should only be taken with advisor or instructor approval.

CS 509. Design of Software Systems

This course focuses on the high-level design aspects of software engineering. Included are architectural and interface design. Within architectural design, the topics covered are Yourdan structured design, Jackson structured design and object-oriented design. When possible, real time extensions are discussed. Sufficient coverage of the areas of requirements specification and testing is given to support the above topics. (Prerequisites: Knowledge of a recursive high-level language and data structures. An undergraduate course in software engineering is desirable.)

CS 513/EE 506. Introduction to Local and Wide Area Networks

This course provides an introduction to the theory and practice of the design of computer and communications networks, including the ISO seven-layer reference model. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types, including local area and wide area networks, are introduced, as well as evolving network technologies. The theory, design, and performance of local area networks are emphasized. The course includes an introduction to queueing analysis and network programming. (Prerequisites: A knowledge of the C programming language is assumed. CS 504 or EE 502 or equivalent background in probability may be taken concurrently.)

CS 514. Advanced Systems Architecture

(Same as EE 572) See EE 572 course description on page 73.

CS 515 . Multiple Processor and Distributed Systems

This course covers the principles of the design and implementation of multiple processor computer systems, case studies of tightly and loosely coupled systems, interprocessor communications software and operating systems, performance and reliability calculations, concurrent programming languages and data flow architectures. (Prerequisites: A good working knowledge of single processor computer systems (EE 572) and single processor operating systems (CS 502). The ability to program in a high level block structured language (Pascal or C) is required for the project and a prior course in networks such as EE 506 is recommended.)

CS 525. Topics in Computer Science

A topic of current interest is covered in detail. (Prerequisites: Vary with topic.) Please consult the department for a current listing of selected topics in this area.

CS 530/EE 530. High Performance Networks

This course is an in-depth study of the theory, design and performance of high speed networks. Topics include specific high performance network implementations and emerging technologies, including multimedia networks and quality of service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queueing models. (Prerequisite: CS 513/EE 506.)

CS 531. System Simulation

The theory and design of discrete simulations are discussed. Other topics are random number generations, analysis of output, and optimization. (Prerequisites: CS 504 or equivalent background in probability, and some background in statistics.)

CS 533/EE 581. Modeling and Performance Evaluation of Network and Computer Systems

Methods and concepts of computer and communication network modeling and system performance evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service, and priority systems; work load characterization; performance evaluation problems. (Prerequisites: CS 504 or EE 502 or equivalent background in probability.)

CS 534. Artificial Intelligence
This course gives a broad survey of artificial intelligence. Several basic techniques such as search methods, formal proofs and knowledge representation are covered. Selected topics involving the applications of these tools are investigated. Such topics might include natural language understanding, scene understanding, game playing, learning and planning. (Prerequisites: A familiarity with data structures and a recursive high-level language. Knowledge of LISP is an advantage.)

CS 535. Advanced Topics in Operating Systems
This course discusses advanced topics in the theory, design and implementation of operating systems. Topics will be selected from such areas as performance of operating systems, distributed operating systems, operating systems for multiprocessor systems, and operating systems research. (Prerequisites: CS 502 and CS 504 or equivalent background in probability.)

CS 536. Programming Language Design
This course discusses the fundamental concepts and general principles underlying current programming languages and models. Topics include control and data abstractions, language processing and binding, indeterminacy and delayed evaluation, and languages and models for parallel and distributed processing. A variety of computational paradigms are discussed: functional programming, logic programming, object-oriented programming and data flow programming. (Prerequisites: Student is expected to know a recursive programming language and to have an undergraduate course in data structures.)

CS 537. Advanced Compiler Design
A study of modern compiler techniques with emphasis on compiler generators. Formal, theoretical issues underlying compilers are investigated, concentrating on those topics which are at the forefront of current compiler technology. Focus is on the "back end" of compilers. (Prerequisites: Basic knowledge of compiler construction, automata and formal language theory and a thorough understanding of the constructs in modern programming languages.)

CS 538. Expert Systems
The course will review expert knowledge-based problem-solving systems. It will concentrate on an analysis of the architecture, knowledge and problem-solving style of each system in order to classify and compare them. For each system an attempt will be made to evaluate its contribution to our understanding of problems that expert systems can tackle. (Prerequisite: CS 534 or equivalent, or permission of the instructor.)

CS 539. Machine Learning
The focus of this course is machine learning for knowledge-based systems. It will include reviews of work on similarity-based learning (induction), explanation-based learning, analogical and case-based reasoning and learning, and knowledge compilation. It will also consider other approaches to automated knowledge acquisition as well as connectionist learning. (Prerequisite: CS 534 or equivalent, or permission of the instructor.)

CS 540. Artificial Intelligence in Design
The main goal of this course is to obtain a deeper understanding of what "design" is, and how AI might be used to support and study it. Students will examine some of the recent AI-based work on design problem-solving. The course will be run in seminar style with readings from the current literature and with student presentations. The domains will include electrical engineering design, mechanical engineering design, civil engineering design, and software design (i.e., automatic programming). This course will be of interest to those wanting to prepare for research in design, or those wishing to increase their understanding of expert systems. Graduate students from departments other than computer science are welcome. (Prerequisites: Knowledge of artificial intelligence is required. This can only be waived with permission of the instructor).

CS 542. Database Management Systems
An introduction to the theory and design of database management systems. Topics covered include internals of database management systems, fundamental concepts in database theory, and database application design and development. In particular, logical design and conceptual modeling, physical database design strategies, relational data model and query languages, query optimization, transaction management and distributed databases. Typically there are hands-on assignments and/or a course project. Selected topics from the current database research literature may be touched upon as well. (Prerequisite: CS 504 or permission of the instructor.)

CS 543. Computer Graphics
This course examines typical graphics systems, both hardware and software, design of low level software support for raster displays, 3-D surface and solids modeling, hidden line and hidden surface algorithms, realistic image rendering including shading, shadowing, reflection, refraction, and surface texturing. (Prerequisites: A familiarity with data structures, a recursive high-level language, and linear algebra. CS 509 would be helpful.)

CS 544. Compiler Construction
A general approach to the design of language processors is presented without regard for either the source language or target machine. All phases of compilation and interpretation are investigated in order to give the student an appreciation for the overall construction of a compiler. Typical projects may include implementation of a small compiler for a recursive or special-purpose language. (Prerequisites: A knowledge of several higher level languages and at least one assembly language. The material in CS 503 is helpful.)

CS 545. Digital Image Processing
(Same as EE 545) This course presents fundamental concepts of digital image processing and an introduction to machine vision. Image processing topics will include visual perception, image formation, imaging geometries, image transform theory and applications, enhancement, restoration, encoding and compression. Machine vision topics will include feature extraction and representation, stereo vision, model-based recognition, motion and image flow, and pattern recognition. Students will be required to complete programming assignments in a high-level language. (Prerequisites: A working knowledge of undergraduate level signal analysis and linear algebra; familiarity with probability theory is helpful but not necessary.)

CS 549. Computer Vision
This course examines current issues in the computer implementation of visual perception. Topics include: image formation, edge detection, segmentation, shape-from-shading, motion, stereo, texture analysis, pattern classification, and object recognition. We will discuss various representations for visual infor-

mation, including sketches and intrinsic images. (Prerequisites: CS 534, CS 543, CS 545, or the equivalent of one of these courses.)

CS 552. Numerical Methods

(Same as MA 510) See MA 510 course description on page 83.

CS 553. Theory of Computability

This course investigates the principal concerns of computability theory and presents several alternate formulations of the Church-Turing Thesis. Starting where the computability portion of CS 503 leaves off, the interrelationships between mathematics and computation are explored using several different approaches. (Prerequisite: CS 503.)

CS 559. Advanced Topics in Theoretical Computer Science

This version of CS 559 will cover Randomized Algorithnms. It will cover the design and analysis of probabilistic algorithms, which are often simpler or faster than deterministic algorithms. Problem areas will include data structures, graph algorithms and computational geometry. (Prerequisites: a knowledge of probability such as may be acquired in CS 504, and data structures such as may be acquired in CS 507. This course will satisfy the CS 504 distribution requirement.)

CS 561. Advanced Topics in Database Systems

This course covers modern database and information systems as well as research issues in the field. Topics and systems covered may include object-oriented, workflow, active, deductive, spatial, temporal, multimedia databases, as well as semantic data modeling. Also discussed will be recent advances in database systems such as data mining, on-line analytical processing, data warehousing, declarative and visual query languages, multimedia database tools, web and unstructured data sources, and client-server and heterogeneous systems. The specific subset of topics for a given course offering is selected by the instructor. Research papers from recent journals and conferences are used. Group project required. (Prerequisites: CS 542 or equivalent. Expected background includes a knowledge of relational database systems.)

CS 562. Advanced Topics in Software Engineering

This course focuses on the non-design aspects of software engineering. Topics may include requirements specification, software quality assurance, software project management, and software maintenance. (Prerequisite: CS 509.)

CS 563. Advanced Topics in Computer Graphics

This course examines one or more selected current issues in the area of image synthesis. Specific topics covered are dependent on the instructor. Potential topics include: scientific visualization, computational geometry, photorealistic image rendering, and computer animation. (Prerequisite: CS 543 or equivalent.)

CS 577. Advanced Computer and Communications Networks

This course covers advanced topics in the theory, design and performance of computer and communications networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queuing models of networks, routing, flow control, new technologies and protocol standards. The current literature will be used to study new networks concepts and emerging technologies. (Prerequisite: CS 513/EE 506 and CS 533/EE 581.)

CS 578. Cryptography and Data Security

(Same as EE 578) See EE 578 course description on page 73.

CS 595. Computer and Communications Networks Internship

6 credits

(Same as EE 595) This project will provide an opportunity to put into practice the principles which have been studied in previous courses. It will generally be conducted off-campus, and will involve a real-world networking situation. Overall conduct of the Internship will be supervised by a WPI faculty member, and an on-site liaison will direct day-to-day activity. The project must include substantial analysis and/or design related to computer or communications networking, and will conclude with a substantial written report. A public oral presentation must also be made, to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison, and one additional WPI faculty member. Successful completion of the internship will be verified by this committee. For a student from industry, an internship may be sponsored by his or her employer. (Prerequisite: Completion of 12 credits of the CCN program.)

ELECTRICAL & COMPUTER ENGINEERING

EE 502. Analysis of Probabilistic Signals and Systems

Applications of probability theory and its engineering applications. Random variables, distribution and density functions. Functions of random variables, moments and characteristic functions. Sequences of random variables, stochastic convergence and the central limit theorem. Concept of a stochastic process, stationary processes and ergodicity. Correlation functions, spectral analysis and their application to linear systems. Mean square estimation. (Prerequisite: Undergraduate course in signals and systems.)

EE 503. Digital Signal Processing

Discrete-time signals and systems, frequency analysis, sampling of continuous time signals, the z-transform, implementation of discrete time systems, the discrete Fourier transform, fast Fourier transform algorithms, filter design techniques. (Prerequisites: Courses in complex variables, basic signals and systems.)

EE 504. Analysis of Deterministic Signals and Systems

Review of Fourier series and linear algebra. Fourier transforms, Laplace transforms, Z transforms and their interrelationship. State space modeling of continuous-time and discrete-time systems. Cannonical forms, solution of state equations, controllability, observability and stability of linear systems. Pole placement via state feedback, observer design, Lyapunov stability analysis. (Prerequisite: Undergraduate course in signals and systems.)

EE 505. Computer Architecture

This course introduces the fundamentals of computer system architecture and organization. Topics include CPU structure and function, addressing modes, instruction formats, memory system organization, memory mapping and hierarchies, concepts of cache and virtual memories, storage systems, standard local buses, high-performance I/O, computer communication, basic principles of operating systems, multiprogramming, multiprocessing, pipelining and memory management. The architecture principles underlying RISC and CISC processors are presented in detail. The course also includes a number of design projects, including simulating a target machine, architecture using a high level language (HLL). (Prerequisites: Undergraduate course in logic circuits and microprocessor system design as well as proficiency in assembly language and a structured high level language such as C or Pascal.)

EE 506. Introduction to Local and Wide Area Networks

(Same as CS 513.) This course provides an introduction to the theory and practice of the design of computer and commuications networks, including the ISO seven-layer reference model. Analysis of network topologies and protocols, including performance analysis, is treated. Current network types and evolving network technologies are introduced, including local, metropolitan, and wide area networks. The theory, design, and performance of local area networks are emphasized. The course includes an introduction to queueing analysis and network programming. (Prerequisities: A knowledge of the C programming language is assumed. CS 504 or EE 502 or equivalent background in probability; may be taken concurrently. Note: Students who receive credit for EE 573 may not receive credit for EE 506.)

EE 507. Field Concepts in Engineering

This core entry-level graduate course exposes the student to the general mathematical framework of dyadic vector-calculus which is subsequently applied to static and dynamic vector, tensor, and coupled field phenomena. The intent of this course is to provide the foundation necessary for more advanced courses in electromagnetics, acoustic/ultrasonics and fluid dynamics. After the mathematical introduction, the course covers: A) the static and dynamic forms of Maxwell's equations, electromagnetic radiation, array antennas; B) the fundamentals of continuum dynamics, acoustic waves in liquids and isotropic as well as anisotropic solids; C) the coupling between EM and acoustic fields, piezoelectric effect, transducer models. The topics are placed in context with various engineering applications ranging from electromechanical device modeling to nondestructive material evaluation. (Prerequisite: An undergraduate exposure to EM theory and vector calculus.)

EE 508. Telecommunications Policy

This course provides an understanding of some of the major trends and issues involved in the development of U.S. telecommunications and information technology policies. The course highlights the interaction between technology and policy; it will help engineers to accept the reality that in the introduction of new technologies policy considerations often play a more important role than do technological advances. The course traces the historical development of U. S. telecommunications policy from supporting a regulated monopoly to the creation of the current increasingly more competitive and less regulated information market place. Topics explored include: the difficulties involved in assessing newly emerging technologies; regulation and deregulation of the telecommunications and information industries; the past, present and future concept of universal service; the convergence of telecommunications, computer and television technologies to create the information network of the future; current competition in local, long-distance, wireless and multimedia services; issues related to standards, interoperability and intellectual property.

EE 511. Electromagnetic Theory

Introduction to analytical and numerical solution techniques in electromagnetics. Investigations of classical approaches to electrostatic, magnetostatic, quasistatic and dynamic field problems. Review of boundary-value problems and their practical limitations. Introduction of the principles and applications of methods of finite differences and finite elements. (Prerequisite: EE 507 or equivalent.)

EE 512. Acoustic and Ultrasound Engineering

Fundamentals of vibration. The acoustic wave equation; transmission phenomena; absorption and attenuation. Radiation from Acoustic sources; dipole and line source radiation; planar piston source; radiation patterns; beam width; directivity; fields from pulsed transducers; Green's function; diffraction; reciprocity. Techniques for ultrasound modeling. Acoustic waveguides. Ultrasound transducer types and transducer modeling. Transducer characterization and calibration. Acoustic measurements techniques. (Prerequisites: EE 501 and EE 502 or equivalent, or permission of the instructor.)

EE 523. Power Electronics

The application of electronics to energy conversion and control. Electrical and thermal characteristics of power semiconductor devices - diodes, bipolar transistors and thyristors. Magnetic components. State-space averaging and sampled-data models. Emphasis is placed on circuit techniques. Application examples include dc-dc conversion, controlled rectifiers, high frequency inverters, resonant converters, and excitation of electric machines. (Prerequisites: EE 3204 and EE 500.)

EE 524. Advanced Analog Integrated Circuit Design

This course is an introduction to the design of analog and mixed analog-digital CMOS integrated circuits for communication and instrumentation applications. An overview of the CMOS fabrication process shows the differences between discrete and integrated circuit design. The MOS transistor is reviewed with basic device physics and the development of circuit models in various operating regions. The use of SPICE simulation in the design process will be covered. Integrated MOS amplifier circuits are developed with an emphasis on understanding performance advantages and limitation in such areas as speed, noise, and power dissipitation. Simple circuits are combined to form the basic functional building blocks such as the op-amp, comparator, voltage reference, etc. These circuit principles will be explored in an IC design project, which may be fabricated in a commercial analog CMOS process. Examples of possible topics include: sample-and-hold (S/H) amplifier, analog-to-digital (A/D) and digital-to-analog (D/A) converters, phase locked loop (PLL), voltage controlled escillator, phase detector, switched capacitor and continuous time filters, and sampled current techniques.

(Prerequisite: Background in analog circuits both at the transistor and functional block (op-amp, comparator, etc.) level. Also familiarity with techniques such as small-signal modeling and analysis in the s-plane using Laplace transforms. Undergraduate course equivalent background EE 3204; EE 4902 helpful but not essential).

EE 529.Selected Topics in Electronic System Design

Courses in this group are devoted to the study of advanced topics in electronic system design.

EE529B. Analog Circuit Design and Intuition

This course is intended to develop simple design approaches and intuitive techniques for use in the analysis and design of complex electronic circuits. These techniques complement detailed analysis and simulation approaches and enable the designer both to quickly generate an approximate solution and to validate answers produced by the more complex approaches. The course outlines some ways of thinking about circuits and mechanical and thermal systems through the use of models and scaling laws. Specific topics include: energy methods applied to electrical and mechanical circuits; open circuit time constants in bipolar amplifier design; short circuit time constants in BJT amplifier design; high gain amplifiers; magnetic circuits and scaling; thermal aspects of high power devices; control issues in switching power converters; oscillators and phase-locked loops. Students will perform a design project and will make use of simulation tools. (Prerequisites: Undergraduate knowledge of solid state devices and electronics design, control systems, electromagnetics.)

EE 529C. Noise in Analog Circuit Design

This course will cover all aspects of noise in the design and analysis of analog and mixed signal circuits and systems. The course begins with a review of techniques from the analysis of probabilistic signals and systems, applying these techniques in the context of analog circuits. Then the fundamental sources of noise will be covered, primarily thermal noise and shot noise. Noise models for passive and active devices will be developed. Examples from the application and design of amplifier circuits will be used to illustrate the design of low noise systems. Issues in mixed signal (analog-digital and digital-analog) systems, such as aliasing and quantization noise, will also be discussed. Measurement techniques for verifying low noise performance will be described. Finally, practical issues will be covered, such as shielding to prevent interference, and proper grounding to avoid coupling of digital noise into sensitive analog signals.

(Prerequisite: EE 502 Undergraduate courses in microelectronics and signal & systems).

EE 530. High Performance Networks

(Same as CS 530.) This course is an in-depth study of the theory, design and performance of high speed networks. Topics include specific high performance network architectures and protocols and emerging technologies, including multimedia networks and quality of service issues. Topics associated with interconnecting networks such as bridges and routers will also be discussed. Performance analysis of networks will include basic queueing models. (Prerequisite: EE 506/CS 513.)

EE 531. Principles of Detection and Estimation Theory

Detection of signals in noise; optimum receiver principles; M-ary detection; matched filters; orthogonal signals; and representations of random processes. MAP and maximum likelihood estimation. Wiener filtering and Kalman filtering. Channel considerations: pre-whitening, fading, and diversity combining. (Prerequisites: EE 501 concurrently, EE 502, EE 500 or equivalent.)

EE 532. Digital Communications: Modulation and Coding

Studies various modulation techniques and coding schemes for digital communications over additive white Gaussian noise channels. Overview of the communication networks and relation to link design and modem design technology. Representation of bandpass signals. Binary and M-ary signaling, basic modulation techniques: PSK, FSK, PAM, QAM and MSK. Timing and phase recovery. Introduction to information theory, source coding and channel coding. Signaling with coded waveforms, soft decision and hard decision block codes, convolutional codes, and Trellis Code Modulation. Characterization of time dispersive band-limited channels and intersymbol interference (ISI). (Prerequisite: EE 502.)

EE 533. Advances in Digital Communication

Methods for ISI reduction: linear, decision feedback, pass band, and fractionally spaced equalizers; maximum likelihood sequence estimation (MLSE). Fast start-up equalization, blind equalization, and echo-cancellation. Characterization of fading multipath channels such as troposcatter, HF, microwave line-of-sight, urban and indoor radio. Digital signaling over fading multipath channels. Methods to improve performance in fading multipath channels: diversity combining, coding, and equalization. Introduction to spread spectrum communication: code division multiple access, performance in fading channels. Multiple access techniques in radio networks. (Prerequisite: EE 532 or equivalent).

EE 534. Adaptive Space-Time Filtering and Spectral Estimation

This course presents adaptive algorithms used in spatial beamforming and temporal filtering. It also includes algorithms used in spectral estimation. Topics covered include: single channel (single sensor) temporal processing, and multi-sensor/multi-channel spatial-temporal processing, FFT based, nonparametric algorithms, channel estimation, Welch's method, parametric spectral estimation, autoregressive modeling, Levinson-Durbin algorithms, Burge algorithm and maximum entropy method, lattice structures, and adaptive transversal filters. It also covers the LMS and RLS algorithm, algorithms based on parameter estimation using ML techniques, direction finding, conjugate gradient descent algorithms, Matrix decompositions, QR and SVD, and subspace tracking algorithms will also be covered. (Prerequisite: EE 502 and EE 503. 531 is recommended).

EE 535. Telecommunications Transmission Technologies

This course introduces the principal technologies used to implement the physical networking layer. These include high-speed electronic pulse shapers and receivers, optical sources, detectors, fiber media, active optical elements, RF devices and systems, and the related protocols and modulation schemes for reliable and multi-user communications (time, frequency, space, and code-division multiplexing, error correction coding, spectral re-use, etc.). The course includes laboratory experiments. (Prerequisites: EE 502 or CS 504; undergraduate-level understanding of signal and circuit theory.)

EE 537. Advanced Computer and Communications Networks

(Same as CS 577) This course covers advanced topics in the theory, design and performance of computer and communication networks. Topics will be selected from such areas as local area networks, metropolitan area networks, wide area networks, queuing models of networks, routing, flow control, new technologies and protocol standards.
The current literature will be used to study new networks concepts and emerging technologies. (Prerequisite: EE 506/CS 513 and EE 581/CS 533.).

EE 538. Wireless Information Networks

Overview of wireless information networks and personal communications systems: digital cellular, wireless PBX, cordless phone, wireless LAN, and mobile data, multimedia wireless and directions of the future. Radio propagation modeling for urban and indoor radio channels, coverage interface and cell size. Modulation techniques for efficient use of bandwidth resources. Methods to increase the data rate: antenna diversity and sectorization, adaptive equalization, multi-rate transmission, and multiamplitude phase modulation. Spread spectrum for digital cellular, personal communications and wireless LAN applications. TDMA, CDMA, ALOHA, and CSMA, DECT, GSM, USDC, JDC, IEEE 802.11, WINForum, and HIPERLAN. (Prerequisite: Background in networks. Familiarity with probability, statistics and signal processing).

EE 539. Selected Topics in Communication Theory and Signal Processing

Topics from the following: sensitivity and error analysis in linear systems; band-limited signals; the uncertainty principle; bandwidth compression, nonstationary processes; radio and inter-symbol interference. Current problems in digital and analog communications; two-dimensional Fourier analysis; pattern recognition; Fourier optics. Time-series analysis, radar signals, graph theory, and information theory. The content of this course will change from year to year.

EE 539A. Real-Time Digital Signal Processing

This course develops the ability to implement digital signal processing algorithms in rea time. Topics: Architectures of digital signal processors, with an emphasis on TMS320C6x (C6x). Fixed-and floating-point processors. The VLIW architecture. Real-time implementation of algorithms including: waveform generation, digital and adaptive filters, FFT, multirate processing. Input and Output considerations. DSP tools and techniques. Programming using C/C++, with some assembly code. Final project required with real-time application usingC6x. Laboratory exercises. (Prerequisite: EE 503 or Permission of Instructor.)

EE 539S. Mobile Data Networking

(Same as CS 525W) This course presents the principles of wireless data communications by introducing the state-of-the-art network architectures, standards and products and explaining the key factors in evolution of this industry. Overview of wireless networks. Architecture of existing mobile date networks: ARDIS, Mobitex, TETHRA, Merticom, CDPD and GPRS. Wireless LAN technologies: 802.11, HIPERLAN, and wireless ATM. Effects of Mobility on different ISO layers. Physical layer options. MAC layer in mobile environments. Issues in mobile computing. Mobile IP, IP-v6, and DHCP. Mobility gateway technologies: MASE and eNetwork. Inter-tech roaming and handover for wireless data networks. (Prerequisite: Familiarity with communication networks (EE 506 or similar)
is desirable.)

EE 541. Modern Control

Theory Modern deterministic linear optimal control strategies for continuous and discrete-time systems are studied. Emphasis is on the state-space system description and multiple-input, multiple-output systems. Topics include: linearization of nonlinear systems, model reduction, pole assignment using state feedback, design and noninteracting (decoupled) systems, performance indices and specifications, deterministic linear optimal regulators, the Riccati equation and computational considerations, state reconstruction (full and reduced order observers), optimal linear output feedback control systems, and comparison of optimal and classical controllers. Where possible, examples from the current literature are used. (Prerequisites: EE 500 or equivalent, plus an undergraduate course in integral and differential calculus.)

EE 545. Digital Image Processing

(Same as CS 545) See CS 545 course description on page 68.

EE 549. Selected Topics in Control

Courses in this group are devoted to the study of advanced topics in the formulation and solution of theoretical or practical problems on modern control.

EE 559. Selected Topics in Energy Systems

Courses in this group are devoted to the study of advanced topics in energy systems. Typical topics include optimal power flow, probability methods in power systems analysis, surge phenomena, design of electrical apparatus, transient behavior of electric machines, and advanced electromechanical energy conversion.

EE 565. Physics and Technology of Integrated Semiconductor Devices

This course introduces a student to the physics of planar devices and devlops an understanding of the limitations of device performance that result from the current planar technology. The course primarily considers silicon-based devices and technology although the extensions to other systems in included. Solid-state technology: vapor phase growth, thermal oxidation, ion implantation, solid-state diffusion; theory of: pn-junctions, bi-polar transistors, field-effect transistors, metal insulator-semiconductor devices. (Prerequisite: Undergraduate background in semiconductor devices).

EE 566. VLSI Design

VLSI Design introduces computer engineers and computer scientists to the techniques, methodologies and issues involved in conceptual and physical design of complex, digital, integrated circuits. The course presupposes knowledge of computer systems and hardware design such as found in EE 505, but does not assume detailed knowledge of transistor circuits and physical electronics. (Prerequisite: EE 505 or equivalent.)

EE 569. Selected Topics in Solid State

Courses in this group are devoted to the study of advanced topics in solid state, for example: degenerate semiconductors, many-body theory, elastic effects and phonon conduction, solar cells. To reflect changes in faculty research interests these courses may be modified, or new courses may be added.

EE 572. Advanced Systems Architecture

(Same as CS 514) This course covers techniques such as caching, hierarchical memory, pipelining, and parallelism that are used to enhance the performance of computer systems. It compares and contrasts different approaches to achieving high performance used in machines ranging from advanced microprocessors to vector supercomputers (CRAY, CYBER). It also illustrates how these techniques are applied in massively parallel SIMD machines (DAP, Connection Machine). In each case the focus is on the combined hardware /software performance achieved and the interaction between application demands and hardware /software capabilities. (Prerequisites: This course assumes the material covered in EE 505. The student should also have a background in computer programming and operating systems (CS 502). Familiarity with basic probability and statistics such as EE 502 or MA 541 is recommended.)

EE 574. VHDL Modeling and Synthesis

This is an introductory course on the VHDL (VHSIC Hardware Description Language) for students with no background in VHDL or hardware modeling. In this course we will examine some of the important features of VHDL. The course will enable students to design, simulate, model and synthesize digital designs. The data flow, structural, and behavioral modeling techniques will be discussed and related to how they are used to design combinational and sequential circuits. The use of test benches to exercise and verify the correctness of hardware models will also be described. Course projects will involve the modeling and synthesis of systems using the ECE department VHDL design tools. (Prerequisites: Logic circuits, programming in a high level language (such as C or Pascal), and a computer architecture course such as EE 505.)

EE 578. Cryptography and Data Security

(Same as CS 578) This course gives a comprehensive introduction into the field of cryptography and data security. The course begins with the introduction of the concepts of data security, where classical algorithms serve as an example.

Different attacks on cryptographic systems are classified. Some pseudo-random generators are introduced. The concepts of public and private key cryptography is developed. As important representatives for secret key schemes, DES and IDEA are described. The public key schemes RSA, ElGamal, and systems based on elliptic curves are then developed. Signature algorithms, hash functions, key distribution and identification schemes are treated as advanced topics. Some advanced mathematical algorithms for attacking cryptographic schemes are discussed. Application examples will include a protocol for security in a LAN and a secure smart card system for electronic banking. Special consideration will be given to schemes which are relevant for network environments. For all schemes, implementation aspects and up-to-date security estimations will be discussed. (Prerequisites: Working knowledge of "C"; an interest in discrete mathematics and algorithms is highly desirable. Students interested in a further study of the underlying mathematics, may register for MA 4891 (B term) where topics in modern Algebra relevant to cryptography will be treated.)

EE 579. Selected Topics in Computer Engineering

Courses in this group are devoted to the study of advanced topics in computer engineering such as: real time intelligent systems, VLSI design, high-level languages.

EE 579R. Advanced Cryptography

This course provides deeper insight into areas of Cryptography which are of great practical and theoretical importance. The three areas treated are: Detailed analysis and the implementation of crypto-algorithms, advanced protocols, and modern attacks against cryptographic schemes. The first part of the lecture focuses on public key algorithms, in particular ElGamal, elliptic curves, and Diffie-Hellman key exchange. The underlying theory of Galois fields will be introduced. Implementation of performance security aspects of the algorithms will be looked at. The second part of the course deals with advanced protocols. New schemes for authentication, identification, and zero-knowledge proof will be introduced. Some complex protocols for real-world application such as key distribution in networks and for smart cards will be introduced and analyzed. The third part will look into state-of-the-art cryptoanalysis (i.e., ways to break cryptosystems). Brute force attacks based on special purpose machines, the baby-step giant-step, and the Pohlig-Hellman algorithms, will be discussed.

EE 579S. Computer Security

This course provides a comprehensive introduction to the field of computer security. Security architectures and their impact on computers are examined. Critical computer security aspects are identified and examined from the standpoints of both the user and the attacker: physical security, communications security, system security, and operational security. Computer system vulnerabilities are examined, and mitigating approaches are identified and evaluated. Concepts and procedures for computer and computer network risk analysis are introduced. An overview of computer security statutes and case law is presented. The course emphasizes a timely approach, maintained by using recent examples of computer attacks and the resources available to deal with the rapidly changing framework of computer security. (Prerequisities: Working knowledge of computers, basic computer networks, and a programing language.)

EE 579T. Network Security

This course provides a comprehensive introduction to the field of network security. Network architectures and protocols and their impact on security are examined. Critical network security aspects are identified and examined from standpoints of both the user and the attacker. Network vulnerabilities are examined, and mitigating approaches are identified and evaluated. Concepts and procedures for network risk analysis are introduced. Integration of network and computer security is introduced. An overview of statutes and case law affecting network security is presented. The course emphasizes a timely approach, maintained by using recent examples of network vulnerability. (Prerequisites: working knowledge of computers, basic computer networks, computer security, and a programming language.)

EE 581. Modeling and Performance Evaluation of Network and Computer Systems

(Same as CS 533.) Methods and concepts of computer and communication network modeling and system performance evaluation. Stochastic processes; measurement techniques; monitor tools; statistical analysis of performance experiments; simulation models; analytic modeling and queueing theory; M/M, Erlang, G/M, M/G, batch arrival, bulk service, and priority systems; work load characterization; performance evaluation problems. (Prerequisites: CS 504 or EE 502 or equivalent background in probability.)

EE 595. Computer and Communications Networks Internship

6 credits

(Same as CS 595) This project will provide an opportunity to put into practice the principles which have been studied in previous courses. It will generally be conducted off-campus, and will involve a real-world networking situation. Overall conduct of the Internship will be supervised by a WPI faculty member, and an on-site liaison will direct day-to-day activity. The project must include substantial analysis and/or design related to computer or communications networking, and will conclude with a substantial written report. A public oral presentation must also be made to both the host organization and a committee consisting of the supervising faculty member, the on-site liaison, and one additional WPI faculty member. Successful completion of the internship will be verified by this committee. For a student from industry, an internship may be sponsored by his or her employer. (Prerequisite: Completion of 12 credits in the program.)

EE 596A & EE 596B. Graduate Seminar

The presentations in the graduate seminar series will be of tutorial nature and will be presented by recognized experts in various fields of electrical and computer engineering. All full-time graduate students will be required to take both seminar courses, EE 596A and EE 596B, once during their graduate studies in the Electrical and Computer Engineering Department. The course will be given pass/fail. (Prerequisite: Graduate standing.)

EE 597. Independent Study

Approved study of a special subject or topics selected by the student to meet his or her particular requirements or interests. Can be technical in nature or a review of electrical and computer engineering history and literature of importance and permanent value. (Prerequisite: B.S. in EE or equivalent.)

EE 598. Directed Research

Each student will work under the direct supervision of a member of the department staff on an experimental or theoretical problem which may involve an extensive literature search, experimental procedures, and analysis. A comprehensive report in the style of a technical report or paper and an oral presentation are required. (A maximum of two registrations in EE 598 is permitted.) (Prerequisite: Graduate standing.)

FIRE PROTECTION ENGINEERING

FPE 510. Flammability Tests, Codes and Standards

Code-related fire test standards will be presented at a level appropriate for fire protection engineers in a format which includes background on perceived need to regulate, analysis of the value and limitation of test methodology and effectiveness of code requirements to control combustible materials and mitigate particular fire hazards. Fire test standards selected for discussion provide data and results which relate to surface flame spread, fire penetration, smoke obscuration, toxic potency of combustion products and rate of heat release for products and systems including interior finish, wall and floor assemblies, thermal insulation, furniture, bedding and draperies.

FPE 520. Fire Dynamics II

Advanced topics in fire dynamics, combustion and compartment fire behavior will be discussed within a framework of modeling fire and its effects. Topics include computer modeling of pre-flashover and post-flashover compartment fires, burning characteristics of polymers and other fuels, the effect of fire retardants, products of combustion generation, flame spread models, plume and ceiling jet models and overall toxicity assessment. Some familiarity with computer programming is recommended. (Prerequisite: FPE 521 or permission of the instructor.)

FPE 521. Fire Dynamics I

This course introduces students to fundamentals of fire and combustion and is intended to serve as the first exposure to fire dynamics phenomena. The course includes fundamental topics in fire and combustion such as thermodynamics of combustion, fire chemistry, premixed and diffusion flames, solid and liquid burning, ignition, plumes and ceiling jets. These topics are then used to develop the basis for introducing compartment fire behavior, pre- and post-flashover conditions and smoke movement. (Prerequisites: Undergraduate chemistry, thermodynamics or physical chemistry, fluid mechanics and heat transfer.)

FPE 553. Fire Protection Systems

This course provides an introduction to automatically activated fire suppression and detection systems. A general overview is presented of relevant physical and chemical phenomena and commonly used hardware in automatic sprinkler, gaseous agent, foam and dry chemical systems. Typical contemporary installations and current installation and approval standards are reviewed. (Prerequisites: Undergraduate courses in chemistry, fluid mechanics and either thermodynamics or physical chemistry.)

FPE 554. Advanced Fire Suppression

Advanced topics in suppression systems analysis and design are discussed with an aim toward developing a performance based understanding of suppression technology. Automatic sprinkler systems are covered from the standpoint of predicting actuation times, reviewing numerical methods for hydraulic analyses of pipe flow networks and understanding the phenomenology involved in water spray suppression. Special suppression systems are covered from the standpoint of two phase and non-Newtonian pipe flow and simulations of suppression agent discharge and mixing in an enclosure. (Prerequisite: FPE 553 or special permission of instructor.)

FPE 555. Detection, Alarm and Smoke Control

Principles of fire detection using flame, heat and smoke detector technology are described. Fire alarm technology and the electrical interface with fire/smoke detectors are reviewed in the context of contemporary equipment and installation standards. Smoke control systems based on buoyancy and HVAC principles are studied in the context of building smoke control for survivability and safe egress. (Prerequisites: FPE 553. Also FPE 521 which can be taken concurrently.)

FPE 563. Risk Management

(Same as MG 527) See MG 527 course description on page 77.

FPE 565. Firesafety Engineering Evaluation

This course develops techniques to evaluate the firesafety performance of a variety of facilities of the built environment and to produce management plans for decision making. The framework for this course is a firesafety engineering method which decomposes the firesafety system into discrete elements that can be used for quantitative evaluation using a variety of fire protection engineering and fire science materials. (Prerequisites: FPE 521, FPE 553 and FPE 570.)

FPE 570. Building Firesafety I

This course focuses on the presentation of qualitative and quantitative means for firesafety analysis in buildings. Fire test methods, fire and building codes and standards of practice are reviewed in the context of a systematic review of firesafety in proposed and existing structures.

FPE 571. Building Firesafety II

This course covers practical applications of fire protection engineering principles to the design of buildings. Both compartmented and noncompartmented buildings will be designed for criteria of life safety, property protection, continuity of operations, operational management and cost. Modern analytical tools as well as traditional codes and standards are utilized. Interaction with architects, code officials and an awareness of other factors in the building design process are incorporated through design exercises and a design studio. (Prerequisites: FPE 553, FPE 521 and FPE 570 or special permission of the instructor.)

FPE 572. Failure Analysis

Development of fire investigation and reconstruction as a basis for evaluating and improving firesafety design. Accident investigation theory and failure analysis techniques such as fault trees and event sequences are presented. Fire dynamics and computer modeling are applied to assess possible fire scenarios and the effectiveness of fire protection measures. The product liability aspects of failure analysis are presented. Topics include products liability law, use of standard test methods, warnings and safe product design. Application of course materials is developed through projects involving actual case studies. (Prerequisite: FPE 521 or special permission of the instructor.)

FPE 573. Industrial Fire Protection

Principles of fire dynamics, heat transfer and thermodynamics are combined with a general knowledge of automatic detection and suppression systems to analyze fire protection requirements for generic industrial hazards. Topics covered include safe separation distances, plant layout, hazard isolation, smoke control, warehouse storage and flammable liquid processing and storage. Historic industrial fires influencing current practice on these topics are also discussed. (Prerequisites: FPE 553, FPE 521 or special permission of the instructor.)

FPE 574 (CM 594). Process Safety Management

This course provides basic skills in state-of-the-art process safety management and hazard analysis techniques including Hazard and Operability Studies (HAZOP), Logic Trees, Failure Modes and Effects Analysis (FMEA) and Consequence Analysis. Both qualitative and quantitative evaluation methods will be utilized. Following a case study format, these techniques along with current regulatory requirements will be applied through class projects addressing environmental health, industrial hygiene, hazardous materials, fire or explosion hazard scenarios. (Prerequisite: An undergraduate engineering or physical science background.)

FPE 575. Explosion Protection

Principles of combustion explosions are taught along with explosion hazard and protection applications. Topics include a review of flammability limit concentrations for flammable gases and dusts; thermochemical equilibrium calculations of adiabatic closed vessel deflagration pressures and detonation pressures and velocities; pressure development as a function of time for closed vessels and vented enclosures; the current status of explosion suppression technology; and vapor cloud explosion hazards.

FPE 580. Special Problems

Individual or group studies on any topic relating to fire protection may be selected by the student and approved by the faculty member who supervises the work.

FPE 581. Seminar

0 credits

Reports on current advances in the various branches of fire protection.

FPE 587. Fire Science Laboratory

This course provides overall instruction and hands-on experience with fire science related experimental measurement techniques. The objective is to expose students to laboratory-scale fire experiments, standard fire tests and state-of-the-art measurement techniques. The Lateral Ignition and Flame Transport (LIFT) apparatus, state-of-the-art smoke detection systems, closed-cup flashpoint tests and gas analyzers are among the existing laboratory apparatus. Fire related measurement techniques for temperature, pressure, flow and velocity, gas species and heat fluxes, infrared thermometry, Laser Doppler Velocimetry (LDV) and Laser Induced Fluorescence (LIF) will be reviewed. (Prerequisite: FPE 521.)

FPE 590. Thesis

Research study at the M.S. level.

FPE 592. Graduate Project

This activity requires the student to demonstrate the capability to integrate advanced fire-safety science and engineering concepts into the professional practice environment. The work may be accomplished by individuals or small groups of students working on the same project. This practicum requires the student to prepare detailed, written technical reports and make oral presentations to communicate the results of their work.

FPE 690. Ph.D. Dissertation

MANAGEMENT

MG 501. Financial Accounting

2 credits

This course introduces the conceptual framework and requirements of corporate financial reporting. Topics covered include the accounting cycle, the required financial statement, how the reporting process classifies, presents, and values the operations, resources, and commitments of the firm. Additional discussion centers on how to analyze accounting choices to support the goals of the firm and how to evaluate a firm's operations through trend ratio analysis. Where appropriate, emphasis is given to technologically oriented firms.

MG 502. Finance

2 credits

This course introduces students to the foundations of modern finance. The student is expected to gain an understanding of the time value of money, basic security valuation, investment criteria, capital market history, portfolio theory, and exchange rate risk. These topics are taught using a problem oriented approach with an emphasis on conceptual understanding and the acquisition of the appropriate analytical and quantitative skills. (Prerequisites: MG 501 or equivalent content and a knowledge of college algebra and basic statistics.)

MG 503. Organizational Behavior

2 credits

This course introduces concepts, theories and current research in the effective management of organizations. Topics include the basics of systems thinking, as well as team and group dynamics. The role of perception and motivation in the behavior of the individual is addressed. Cases, workshops, and readings are integrated in a cohesive approach to management problems.

MG 504. Production/Operations Management

2 credits

This course covers techniques and models used to design, plan, and control global manufacturing and service operations. Design topics include location, layout, and the development of strategies for world class operations. Planning and control topics include forecasting, aggregate planning, materials management, scheduling, and quality control. Students should be familiar with basic statistical concepts such as calculating mean and variance.

MG 505. Quantitative Methods

2 credits

This course provides the background by which a modern manager may understand and apply quantitative methods. Topics covered include descriptive state, probability theory, measures of dispersion and hypothesis testing and confidence descriptions. Additional discussion focuses on correlation and regression analysis, as well as analysis of variance and time series mathematics as applied to business analysis.

MG 506. Principles of Marketing

2 credits

This course provides the background by which managers may understand consumer and industrial decision-making. Topics covered include segmentation and target marketing, market research, competitor analysis, marketing information systems. Additional discussion focuses on the development of a marketing plan and positioning of the product. Attention is also paid to product management, new product development, promotion, price and distribution. Both national and global aspects of these issues are discussed.

MG 507. Management Information Systems
2 credits
This course focuses on information technology and management. Topics covered are information technology and organizations, information technology and individuals (privacy, ethics, job security, job changes), information technology within the organization (technology introduction and implementation), business process engineering, and information technology between organizations (electronic data interchange and electronic commerce).

MG 508. Economics of the Firm
2 credits
This course covers the basic concepts of supply and demand. Various forms of business organization (e.g. corporations, partnerships) are discussed. Attention is paid to both consumer behavior (e.g. utility theory) and firm behavior (including production theory and cost analysis). Alternative market structures, including output markets (e.g. competition, monopoly) and inputs (e.g. labor, capital) are addressed. Additional topics include the government regulation of markets (e.g. anti-trust laws), and public and merit goods.

MG 509. Domestic and Global Economic Environment of Business
2 credits
This course addresses the role of government in the economy, including concepts of income redistribution, taxation and stabilization. The fundamentals of aggregate demand and supply are also discussed. Topics include: the concept and measurement of aggregate output and input (e.g. Gross Domestic Product, GDP); Keynesian and post-Keynesian income determination analysis; fiscal policy (including government deficits and the public debt); monetary policy, the role of the Federal Reserve, and the banking system; economic growth; international trade and exchange rate determination.

MG 511. Interpersonal and Leadership Skills for Technological Managers
This course provides a background on the new technological organization, including new employment relationships and organizational forms. Attention is focused on cultural dynamics and diversity including national, global, and ethical issues. The importance of teams and leadership in the networked organ-ization are addressed. Assignments include case analyses, individual and group projects and presentations. (Prerequisite: MG 503, or equivalent content, or consent of instructor.)

MG 512. Creating and Implementing Strategy for Technological Organizations
4 credits
This course focuses on understanding the market and the importance of market research, customer needs, competitor analysis, business environment and forecasting. The development of ethical and effective strategy is discussed, including exploiting and developing the core competencies of the organization. Promoting and developing interfunctional and international communication and cooperation are addressed. Special attention is paid to the integration of emerging technologies. Other areas covered include assessment analysis, including controlling quality and tracking customer response. (Prerequisite: MG 506, or equivalent content or consent of the instructor.)

MG 513. Creating Processes in Technological Organizations
This course introduces students to the critical role of processes in modern technological organizations. This course addresses organizational, technical, and ethical issues related to designing, analyzing, and reengineering business process. Techniques and tools for process design will be covered. Key global processes such as customer service, order fulfillment, and goods/services creation and distribution processes and their enabling information technology are studied in detail. Assignments include case study analyses, computer exercises and a process analysis project. (Prerequisites: MG 504 and MG 507, or equivalent content, or consent of instructor.)

MG 514. Business Analysis for Technological Managers
4 credits
This course provides an understanding of the concepts and tools of business analysis. One major focus emphasizes how accounting information aids the planning, control, decision making, and evaluation of firm operations, through product costing techniques, budgetary planning, control and evaluation of operations using accounting information, and analysis of how accounting information can advance a firm's goals and strategies. This course also provides an introduction to the strategic role of finance and financial management, analysis of company performance, valuation at the project and firm level, the impact of major corporate decisions, the relationships among stakeholders of the firm, the financial implications of corporate restructuring, and cash management. (Prerequisites: MG 501, MG 502, MG 505, MG 506, and MG 508, or equivalent content; or consent of instructor.)

MG 515. Legal and Ethical Context of Technological Organizations
2 credits
This course introduces the student to the nature of American and International law, including the concepts of the judicial and alternative dispute resolution, as well as the constitutional authority to regulate business. Other areas addressed include torts, negligence, and strict liability, ethical decision-making, business and computer crimes, and intellectual property rights. Additionally, discussion focuses on contract, negotiable instruments, liability of principals and agents, securities regulation and investor protection. Employment contracts and worker protection laws, e.g. equal opportunity, labor relations and OSHA, are covered.

MG 516. Graduate Qualifying Project in Management (GQP)
This capstone project, in the area of the Management of Technology, is a self-contained course that integrates management theory and practice and incorporates a number of skills and tools acquired in the M.B.A. curriculum. The project report will be available in the Department. In addition, the material contained within the report will be formally presented to members of the Department, outside sponsors, and other interested parties, and will clearly demonstrate that a number of the desired outcomes described in the mission statement are fulfilled. (Prerequisites: All foundation and core courses, or equivalent content, or consent of instructor.)

MG 526. Case Studies in Financial Management
Intermediate- and advanced-level case studies in financial management. The course employs a case study approach with emphasis on class discussion and participation. Basic concepts of capital budgeting, financial structure, the cost of capital budgeting, financial structure, the cost of capital, and other areas are reviewed. The course stresses more advanced topics such as the capital asset and arbitrage pricing mod-

els, the Modigliani-Miller propositions on the cost of capital, firm valuation, mergers, bankruptcy and international finance. (Prerequisite: MG 502.)

MG 527. Risk Management

(Same as FPE 563) Risk Management is highly interdisciplinary, drawing upon systems engineering, managerial decision making and finance. The basics of risk management, including hazard analysis, risk assessment, risk control and risk financing, are covered. The course is self-contained and includes material from engineering economy, risk assessment and decision analysis. Group projects may draw from fire protection engineering, hazardous waste management and product liability. The projects serve to emphasize important techniques for quantifying risk and the challenge of integrating risk assessment with managerial decision making.

MG 531. Managing Organizational Change

Focuses on the acquisition of diagnostic and implementation skills to bring about smooth transitions in areas of change, with emphasis given to technological change. The course is developed around important theories of change and their appropriate applications in various organizational cultures.

MG 532. Human Resource Management

Presents challenges and issues in the management of an organization's human resources. The course is intended for students with a general interest in management issues, not for specialists in the human resources function. It stresses case studies focusing on current problems of managing the work force due to changing technologies, environmental and social factors, strategic business considerations, and organizational and personal values.

MG 533. Negotiations

Focuses on improving the student's understanding of the negotiation process and effectiveness as a negotiator. Emphasizes issues related to negotiating within and on behalf of organizations, the role of third parties, the sources of power within negotiation, and the impact of gender, culture, and other differences. Conducted in workshop format, combining theory and practice.

MG 53X. Virtual Teams

This course focuses primarily on helping students understand the challenges of working on virtual teams and identify and practice more effective ways to managing those challenges. It is totally web-based and relies on CourseInfo Blackboard to serve as the venue where each cirtual team will meet, work, and learn about the opportunities and pitfalls of virtual team participation.

MG 542. Quality Planning and Control

Focuses on the quality aspects of product design and manufacturing. Topics include total quality management, quality function deployment, poke-yoke systems, statistical process control, capability studies, quality loss function and design of experiments (Taguchi methods). Course assumes familiarity with statistics.

MG 544. Supply Chain Management and Electronic Commerce

This course provides students with a managerial background in supply chain management and its interface with Electronic Commerce (E-commerce). It discusses the role of each element of a supply chain in creating value for the business and the issues involved in integrating and coordinating the elements. Electronic data change (EDI), the Internet, and E-commerce are introduced and their impacts on internal and external value chains are explored. Topics such as competitive operations strategies, outsourcing, purchasing and inbound logistics, inventory management, outbound logisitics, types of electronic commerce, electronic data interchange, virtual integration and others are covered. In addition to the lecture format, students will learn about the factors that lead to successful applications of E-commerce to supply chain management through extensive case studies.

MG 545. Production Systems Design

Focuses on the design and implementation of computer integrated production systems. Topics include: computer-aided design, computer-aided process planning, group technology, programmable machine tools, industrial robotics, automated material handling, computer-aided quality control, computer process control, flexible manufacturing systems, computer-aided production management systems, computer databases and communications networks, and manufacturing systems engineering. (Prerequisite: MG 504 or equivalent content, or consent of instructor.)

MG 546. Managing Technological Innovation

Study of successful innovations and how firms must enhance their ability to develop and introduce new products and processes. The course will discuss a practical model of the dynamics of industrial innovation. Cases and examples will be discussed for products in which cost and product performance are commanding factors. The important interface among R&D/manufacturing/marketing is discussed. International technology transfer and joint venture issues are also considered.

MG 547. Project Management

Presents the specific concepts, techniques and tools for managing projects effectively. The role of the project manager as team leader is examined together with important techniques for controlling cost, schedules and performance parameters. Lectures, case studies and business games are combined to develop skills needed by project managers in today's environment.

MG 548. Productivity Management

Focuses on planning, implementing, measuring, and evaluating productivity improvement efforts in both manufacturing and service organizations, including overall strategies as well as specific techniques for improving productivity. Both the technological and behavioral aspects of productivity improvement are covered.

MG 549. Strategies for Manufacturing Firms

Focuses on developing and implementing strategies for product design and manufacturing that will best support the overall strategy of the firm. Topics include: positioning the product and production system in the industry, making location and capacity decisions, selecting and implementing manufacturing technologies, facilities planning, vertical integration, logistics planning, and developing organizations, cultures, and policies for implementation. Case studies of manufacturing firms are utilized extensively. (Prerequisite: MG 504 or equivalent content, or consent of instructor.)

MG 551. Management Science

Applications of management science techniques to problem areas from manufacturing, finance and marketing. Topics include: uses of mathematical programming, decision analysis, scheduling, waiting lines, project management and simulation. Frequent use is made of computerized procedures for the analysis of formulated models. (Prerequisite: MG 505 or equivalent content or consent of instructor.)

MG 561. Marketing Research

A survey of market research techniques and information management. Effective technology marketing requires timely and accurate market information, analysis, and dissemination. This course will prepare the student to work effectively with secondary data sources, design market research studies, interpret market research results, work effectively with research providers, and understand the dynamics of information use. Topics include: secondary data sources, experimental design, sampling, questionnaire design, the management of field work, qualitative analysis, forecasting, univariate and multivariate data analysis, report dissemination, development of market information systems, factors affecting research use, and ethical issues associated with collecting and using data. (Prerequisites: MG 505 and MG 506 or equivalent content, or consent of instructor.)

MG 562. Technology Transfer & New Product Development

The conversion of technology to commercial products requires an understanding of the markets and effective management of interdepartmental and interorganizational relationships to deal effectively with rapid change and short product life cycles. This course focuses on prelaunch issues in the development of new products. It is an overview of the issues associated with market management and the management of organizational change in discontinuous innovations. Topics include: understanding consumer perceptions of radical innovations, forecasting demand for innovative products, using customers as partners in the design process, managing the integration of marketing with research and development, engineering, and manufacturing, and managing strategic alliances. Knowledge of marketing management is assumed.

MG 563. Marketing of Emerging Technologies

This course is a continuation of the Technology Transfer and New Product Development course, and addresses issues associated with the introduction and management of new products. Topics include: understanding consumer responses to innovation, positioning new products, effective promotion of new products with particular emphasis on online marketing technologies, pricing strategy, securing channels of distribution and channel modification during the product life cycle, product modification and extensions, issues associated with the development and management of brand equity, and dealing with competitive responses. Knowledge of marketing management is assumed. Knowledge of technology transfer and new product development is beneficial but not required.

MG 564. Global Technology Marketing

Extending technology to global markets requires an understanding of consumer behavior in different cultures and effective management of risk and overseas infrastructures. This course addresses the issues associated with technology application in new markets and will include the following topics: consumer behavior differences in international markets and the implications for the marketing mix, cultural differences that affect business practices in new markets, managing exchange rate fluctuation, factors that affect manufacturing and research location, the impact of local government on marketing decision making, and the use of strategic alliances to acquire expertise and manage risk in global market development. Knowledge of marketing management is assumed.

MG 565. Industrial Marketing

Marketing of goods and services to businesses and other organizations for use in their production, and further marketing of goods and services. Topics include management of the field sales force, industrial buying process, distribution channel development and main-tenance, development of new industrial products, pricing and promotion decisions.

MG 566. Marketing and Electronic Commerce

This course discusses the tools and techniques being used today to harness the vast marketing potential of the Internet. It examines various web-based business models for effectively and efficiently using the net as a strategic marketing tool for new products, market research, direct and indirect distribution channels, and marketing communications. The course considers both business-to-consumer and business-to-business applications and explores the major opportunities, limitations, and issues of profiting from the Internet.

MG 571. Database Applications Development

Business applications are increasingly centered around databases and delivery of high-quality data throughout the organization. This course introduces students to the theory and practice of computer based data management. It covers data administration and the design of data tables for computerized databases. Commercially-available databases, management systems and the data models that are the basis for these systems are discussed. The course also covers user interface design and applications development needed to ensure that users with different information needs and computing abilities have easy access to the information they need to perform their organizational tasks. Students will be exposed to commercially available database management systems, such as, MS/Access and SQL Server. As a project during the course, students will design and implement a small database that meets the needs of some real-world business data application.

MG 572. Telecommunications Management and Electronic Commerce

Telecommunications is becoming an integral part of the way work is done in today's business organizations. This course provides students with the technical and managerial background of telecommunications and its applications in electronic commerce. It covers the technical fundamentals of data transmission, local area networks, local internetworking, and enterprise internetworking. The issues involved in developing and managing an organization's telecommunications infrastructure will be discussed. This course will also examine the role of telecommunications technology, especially the Internet, in electronic commerce and survey current topics in electronic commerce. As a course project, students will learn to use commercially available web development tools to design and implement a small web-based business application.

MG 573. System Design and Development

This course introduces students to the concepts and principles of business systems design and analysis. Students will learn to use a visual, object-oriented software development tool, such as Visual Basic, to design and develop small business applications. Traditional structured systems design and analysis techniques as well as advanced object-oriented methods are discussed. The course will also examine the role of computer-assisted software engineering and software project management tools in systems design and analysis.

MG 575. Information and Decision Support Systems

This course analyzes how managers make decisions and the information they need to make these decisions. It revolves around the planning, development, and use of information systems and technologies for delivering high-quality information to managers and for supporting their decision making. The course covers decision support systems, expert systems, group decision support systems, and executive information systems, as well as the information technologies used to develop such systems. Students will analyze case studies, write short papers, design and implement computer systems, and investigate new information technologies for ensuring that high-quality information is accessible to managers when needed.

MG 581. Managerial Economics

Applies economic theory and methodology to managerial decision making. Topics include modeling of demand, production and cost functions and statistical estimation of these functions, risk analysis, market structures and price determination, and the economics of government regulation and anti-trust policy. (Prerequisites: MG 508 and MG 509 or equivalent content, or consent of instructor.)

MG 590. Management and Society

Relationships between organizations and the society of which they are a part. Topics include historical relationships between business, government and society and current and future roles and responsibilities of management. Environmental scanning, including technological, social, political and economic forecasting techniques related to policy planning are also covered.

MG 592. New Venture Management and Entrepreneurship

Management problems associated with the founding of a new enterprise, either as a small business or as part of an existing corporation. Concepts and methodologies for putting together a successful business idea with emphasis on technology-based innovation. Topics include organizational problems, strategies, the management team, legal aspects, sources of financing, marketing problems, accounting, control and budgeting for a new business. Lectures, cases and guest speakers are used. Students are required to complete a term project preparing a business plan.

MG 593. International Management

Problems of firms engaged in international business, including the motivations for production and foreign involvement, control of foreign operations, and the financing of foreign activities. The case method is used extensively to involve students in current issues, problems and decisions facing industrial managers. Background in accounting, finance and economics is assumed.

MG 597. Internship

The Internship is an elective-credit option designed to provide an opportunity to put into practice the principles which have been studied in previous courses. Internships will be tailored to the specific interests of the student. Each internship must be carried out in cooperation with a sponsoring organization (generally from off-campus), and must be approved and advised by a WPI faculty member in the Department of Management. Internships may be proposed by the student or by an off-campus sponsor. The internship must include proposal, design, and documentation phases. Following the internship the student will prepare a report describing his or her internship activities and will make a presentation before a committee including the faculty advisor and a representative from the sponsoring organization. Students are limited to one three-credit, semester length internship experience. The internship may not be completed at the student's place of employment. (Prerequisite: Completion of the required component of the individual student's graduate management degree program.)

MG 598. Data Mining

The past few years have seen an unprecedented explosion in the amount of data collected by business. Commercial enterprises have been quick to recognize the strategic significance of extracting valuable information from these large quantities of data, leading to the emergence of the field of Data Mining. Consequently, within the span of a few years, the software market for data mining is expected to be in excess of $10 billion. Data Mining refers to a family of techniques used to detect "interesting" and "useful" nuggets of relationship/knowledge in data. This course will provide an overview of some commonly used Data Mining methods. Appropriate Data Mining tools will be used throughout the course.

MG 598. Independent Study

Directed in-depth independent study or seminar program following one or more of the core areas of management. Independent study can focus on a major problem in manufacturing, information systems, health systems, energy, government, etc. Each student must have a designated faculty advisor who must approve the subject and methodology in advance. Before registering for Independent Study, students should contact the director of graduate management programs.

MG 598. Intellectual Property Asset Management

This course focuses on identifying and using intellectual property assets for competitive advantage in establishing a new business, or reinforcing and growing an existing business. Students will learn how to create an intellectual property strategy and apply it in all facets of a business. The course provides a practical overview of intellectual property law, including: proprietary information, trade secrets, patents, trademarks, and copyrights as applied to specific case studies and product areas. Included will be analysis of issues involved in transactions with vendors, customers, and third party partners. Through the use of an intellectual property audit, a complete intellectual property policy and procedure will be developed for an emerging business as applicable to specific functions: human resources, purchasing, marketing, research and development and engineering. The identification and valuation of technology assets will be considered for technology transfer through licensing, including franchising. Through the use of real life case studies, this course will concentrate on the practical application of the intellectual property laws to business. This course is complimentary to MG 515, MG 546, MG 562 and MG 563. (Prerequisites: None.)

MG 598. International Finance

This is a survey course in international financial management. The course focuses on both the management of financial operations as well as on the international environment within which the manager operates. Topics of study include international financial markets, foreign exchange markets, exchange rate risk management, international financing, multi-national capital budgeting, multinational capital structure and international banking. The topics are introduced via lecture, class discussions, and case analysis. (Prerequisite: MG 502 or equivalent content, or consent of instructor.)

MG 599 Thesis

6 to 9 credits

Research study at the master's level.

MANUFACTURING ENGINEERING

MFE 500. Current Topics in Manufacturing Seminar

0 credits

This seminar identifies the typical problems involved in a variety of manufacturing operations, and generic approaches for applying advanced technologies to implement operations. Topical areas of application and development such as intelligent materials processing, automated assembly, MRP and JIT scheduling, vision recognition systems, high speed computer networks, distributed computer control of manufacturing processes, and flexible manufacturing systems may be covered. This seminar is coordinated with the undergraduate program in manufacturing engineering.

MFE 510. Control and Monitoring of Manufacturing Processes

Covers a broad range of topics centered on control and monitoring functions for manufacturing, including process control, feedback systems, data collection and analysis, scheduling, machine-computer interfacing, and distributed control. Typical applications are considered with lab work.

MFE 511. Application of Industrial Robotics

(Concurrent with ME 4815) This course introduces the student to the field of industrial automation. Topics covered include: robot specification and selection, control and drive methods, part presentation, economic justification, safety, implementation, product design, and programming languages. The course combines the use of lecture, project work, and laboratories that utilize industrial robots. Theory and application of robotic systems will be emphasized.

MFE 520. Design and Analysis of Manufacturing Processes

The first half of the course covers the axiomatic design method, applied to simultaneous product and process design for concurrent engineering, with the emphasis on process and manufacturing tool design. Basic design principles as well as qualitative and quantitative methods of analysis of designs are developed. The second half of the course addresses methods of engineering analysis of manufacturing processes, to support machine tool and process design. Basic types of engineering analysis are applied to manufacturing situations, including elasticity, plasticity, heat transfer, mechanics and cost analysis. Special attention will be given to the mechanics of machining (traditional, non-traditional and grinding) and the production of surfaces. Students, with the advice and consent of the professor, select the topic for their term project.

MFE 530. Computer-Integrated Manufacturing

(Same as MG 543) An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration. (Prerequisites: Recommended background courses: MG 504, MG 545.)

MFE 540. Design for Manufacturability

The problems of cost determination and evaluation of processing alternatives in the Design-Manufacturing Interface. Approaches for introducing manufacturing capability knowledge into the product design process are covered, with emphasis on part and process simplification, analysis of alternative manufacturing methods based on anticipated volumes, and design for automated assembly.

MFE 594. Special Topics

Theoretical and experimental studies in subjects of interest to graduate students in manufacturing engineering. (Prerequisite: Consent of instructor.)

MFE 594T. Surface Engineering and Tribology

Analysis of surface roughness for understanding surface manufacture, modification and performance is emphasized. Friction, wear and lubrication are studied in the context of manufacturing, materials and mechanical engineering. Students select topics for in-depth reviews.

MFE 598. Directed Research

3 to 6 credits

MFE 599. Thesis Research

Maximum 3 credits

MATERIALS SCIENCE & ENGINEERING

Research - as arranged

Additional acceptable courses, 4000 series, may be found in the Undergraduate Catalog.

MTE 580. Materials Science and Engineering Seminar

Reports on the state-of-the-art in various areas of research and development in materials science and engineering will be presented by the faculty and outside experts. Reports on graduate student research in progress will also be required.

MTE 581. Phase Transformations

Applications of thermodynamics, kinetics and diffusion, to phase transformations. Modeling of materials systems, phase diagrams and invariant reactions are presented. (Prerequisites: ME 4840 and ME 4850 or equivalent.)

MTE 5810. X-Ray and Electron Microscopy

Diffraction theory studied as a basis for understanding and for determining crystal structures of polycrystalline solids. Quantitative phase analysis. Experimental methods applied to materials engineering. (Prerequisite: ME 4840 or equivalent.)

MTE 5811. Physical Ceramics

Examination of the interrelationships among crystal structure, microstructure, processing and properties. Fundamentals of microstructure development; nucleation, grain growth, precipitation, sintering, vitrification. Mechanical, optical, electrical, magnetic properties in various ceramic systems and their relationship to microstructure will be discussed. (Prerequisite: ME 4813.)

MTE 5812. Advanced Microstructural Analysis

Quantitative optical microscopy. Electron microscopy; replica and transmission techniques. Selected topics. Course may be offered by special arrangement. (Prerequisites: ME 3811 and ME 4840 or equivalent.)

MTE 582. Mechanical Behavior of Materials

Topics including plastic deformation, creep, fatigue, fracture, and metal forming are presented and discussed. (Prerequisite: ME 3023 or equivalent.)

MTE 5822/MFE 5822. Solidification Processes

A course designed for in-depth study of industrial processes based on liquid-solid transformations. Fundamentals are developed and applied to commercial processes. The topics covered include: qualitative treatment of casting processes, sand casting, die casting, investment casting, semisolid forming, various welding processes, laser welding, rapid solidification, spray forming, compocasting and other emerging technologies, which utilize liquid-solid transformations. Library and laboratory work will be included.

Suggested preparation: an understanding of heat transfer, fluid flow, solid state diffusion and microscopy. (ES 2001, ES 3003, ES 3004, ME 3811, ME 4840) or equivalent.

Offered in the 2000/2001 academic year and in alternate years thereafter.

MTE 5823/MFE 5823. Particulate Processing of Materials

Particulate processing is used to manufacture net-shaped components from particulate materials as in powder metallurgy (PM), metal injection molding (MIM) and the processing of ceramic and refractory materials. Processing of particulate materials is covered in detail, including atomization to produce powders, compaction, sintering, and post sintering operations. Interfacial issues to control flow and final density are studied, in addition to the fundamentals of phase flow, compaction and densification. Industrial applications and plant trips will augment classroom experience.

Suggested background: (ES 2001, ME 2820, ME 3811, ME 4840) or equivalent.

Offered in the 1999/2000 academic year and alternate years thereafter.

MTE 583. Analytical Methods in Materials Engineering

Heat transfer and diffusion kinetics are applied to the solution of materials engineering problems. Mathematical and numerical methods are developed for solutions to Fourier's and Fick's laws for a variety of boundary conditions. Primary emphasis is given to heat treatment and surface modification processes. (Prerequisites: ME 3811 and ME 4840 or equivalent.)

MTE 584. Polymer Engineering

Structure-property relationships are developed for polymeric materials. Characterization techniques are discussed. Special emphasis is given to the mechanical, corrosion, fracture properties and processing of polymers. Course may be offered by special arrangement. (Prerequisite: ME 4840 or equivalent.)

MTE 5841. Surface Metrology and Tribology

This course examines the methods for measuring and analyzing surface texture (roughness) in order to make functional correlations between the texture and performance, and to improve the understanding of texture-dependent surface phenomena like adhesion,, scattering, fracture, friction and wear. Tribology, the study of friction, lubrication and wear, will be reviewed in the context of surface texture. Selection or surface measurement instruments and analysis methods, including fractal-based analysis, for finding functional correlations, for quality control and for the design of surface textures will be discussed. Examples from a broad range of applications will be discussed, including skin, runways, thermal spray adhesion, hard disks, machining and grinding.

MTE 5842. Corrosion and Corrosion Control

Advanced topics in corrosion. Stress corrosion cracking and hydrogen effects on metals. High temperature oxidation, carburization and sulfidation. Discussions focus on current corrosive engineering problems and research. Course may be offered by special arrangement.

MTE 585. Thermodynamics of Materials

The thermodynamics of surfaces, interfaces and defects in solids is presented. The applications to metals and ceramics are discussed. The application of thermodynamics to electrochemical reactions and reactions between gases and alloys also will be developed. Course may be offered by special arrangement. (Prerequisites: ME 3811 and ME 4840 or equivalent.)

MTE 520. Design and Analysis of Manufacturing Processes

The first half of the course covers the axiomatic design method applied to simultaneous product and process design for concurrent engineering, with emphasis on process and manufacturing tool design. Basic design principles as well as qualitative and quantitative methods of analysis of designs are developed. The second half of the course addresses methods of engineering analysis of manufacturing processes, to support machine tool and process design. Basic types of engineering analysis are applied to manufacturing situations, including elasticity, plasticity, heat transfer, mechanics and cost analysis. Special attention will be given to the mechanics of machining (traditional, non-traditional and grinding) and the production of surfaces. Students, with the advice and consent of the professor, select the topic for their term project.

MTE 554. Composites with Biomedical and Materials Applications

Introduction to fiber/particulate reinforced, engineered and biologic materials. This course focuses on the elastic description and application of materials that are made up of a combination of submaterials, i.e. composites. Emphasis will be placed on the development of constitutive equations that define the mechanical behavior of a number of applications including: biomaterial, tissue, and materials science. (Prerequisites: understanding of stress analysis and basic continuum mechanics.)

MTE 570. Electronic, Magnetic and Optical Materials Science and Processing

This course discusses the fundamentals of materials science and processing for infomation technology devises. Optical, electrical and magnetic properties of materials will be studied. The theory and technology of integrated circuit fabrication will be presented. The focus will be on understanding the underlying physical principles of the unit processes which are the basis for most fabrication steps such as: bulk crystal growth, thin film deposition, lithography, metallization, ion implantation, etching, reliability, electrical behavior and materials device characterization. The emphasis of this course will be on materials processing principles and the relationship with structure, properties and performance.

MTE 594. Special Topics

As arranged. Theoretical or experimental studies in subjects of interest to graduate students in materials science and engineering.

MATHEMATICAL SCIENCES

MA 4451. Boundary Value Problems

Science and engineering majors often encounter partial differential equations in the study of the flow, vibrations, electric circuits, and similar areas. Solution techniques for these types of problems will be emphasized in this course. Topics covered include: derivation of partial differential equations as models of prototype problems in the areas mentioned above, solution of linear partial differential equations by separation of variables, Fourier integrals and a study of Bessel functions. (Prerequisite: A knowledge of ordinary differential equations is assumed.)

MA 501. Engineering Mathematics

This course develops mathematical techniques used in the engineering disciplines. Preliminary concepts will be reviewed as necessary including vector spaces, matrices, and eigenvalues. The principle topics covered will include: Vector Calculus, Fourier Transforms, Fast Fourier Transforms, and Laplace Transformations. Applications of these techniques for the solution of boundary value and initial value problems will be given. The problems treated and solved in this course are typical of those seen in the applications and include the problems of heat conduction, mechanical vibrations and wave propagation. (Prerequisite: A knowledge of ordinary differential equations, linear algebra, and multivariable calculus is assumed.)

MA 503-504. Analysis I & II

Topics covered include open and closed sets, compactness, continuity, upper and lower semicontinuity, Lebesque measure, integration, functions of bounded variation, absolute continuity, the Fundamental Theorem of Calculus for Lebesque integrals, Banach spaces, classical LP spaces, the Holder and Minkowski inequalities, the Riesz-Fischer Theorem, and the Riesz Representation Theorem. (Prerequisite: Basic knowledge of undergraduate analysis is assumed.)

MA 505. Complex Analysis

This course will provide a rigorous and thorough treatment of the theory of functions of one complex variable. The topics to be covered include, complex numbers, complex differentiation, the Cauchy Riemann equations, analytic functions, Cauchy's theorem, complex integration, the Cauchy integral formula, Liouville's theorem, Gauss mean value theorem, Maximum modules theorem, Rouches' theorem, Poisson integral formula, Taylor-Laurant expansions, singularity theory, Conformal mapping with applications, analytic continuation, Schwarz's reflection principle, and elliptic functions. (Prerequisite: A knowledge of advanced calculus.)

MA 508. Mathematical Modeling

This course introduces mathematical model building using dimensional analysis, perturbation theory and variational principles. Models are selected from the natural and social sciences according to the interests of instructor and students. Examples are: planetary orbit, spring-mass systems, fluid flow, isomers in organic chemistry, biological competition, biochemical kinetics, and physiological flow. Computer simulation of these models will also be considered. (Prerequisite: A knowledge of ordinary differential equations and of analysis at the level of MA 501 is assumed.)

MA 509. Stochastic Modeling

This course gives students a background in the theory and methods of probability, stochastic processes and statistics for applications. The course begins with a brief review of basic probability, discrete and continuous random variables, expectations, conditional probability and basic statistical inference. Topics covered in greater depth include generating functions, limit theorems, basic stochastic processes, discrete and continuous time Markov chains, and basic queuing theory including M/M/1 and M/G/1 queues. (Prerequisite: A knowledge of basic probability at the level of MA 3613 and statistics at the level of MA 2612 is assumed.)

MA 510. Numerical Methods

(Same as CS 552) This course is an introduction to modern numerical techniques. It is suitable for both mathematics majors and students from other departments. It covers material not treated in either MA 512 or MA 514, and it introduces the main ideas of those two courses. Topics covered include: interpolation by polynomials, roots of nonlinear equations, approximation by various types of polynomials, orthogonal polynomials, least-squares approximation, trigonometric polynomials and fast Fourier transforms, piecewise polynomials and splines, numerical differentiation and integration, unconstrained optimization including Newton's method and the conjugate direction method, and an introduction to the solution of systems of linear equations and initial value problems for ordinary differential equations. Both theory and practice are examined. Error estimates, rates of convergence, and the consequences of finite precision arithmetic are also discussed. Other topics may include integral equations or an introduction to boundary value problems. In the course of analyzing some of the methods, topics from elementary functional analysis will be introduced. These include the concept of a function space, norms and inner products, operators, and projections. (Prerequisite: Knowledge of undergraduate linear algebra and differential equations, and a higher level programming language is assumed.)

MA 512. Numerical Differential Equations

This course begins where MA 510 ends in the study of the theory and practice of the numerical solution of differential equations. Central topics include a review of initial value problems, including Euler's method, Runge-Kutta methods, multistep methods, implicit methods, and predictor-corrector methods; the solution of two-point boundary value problems by shooting methods and by the discretization of the original problem to form systems of nonlinear equations; numerical stability; existence and uniqueness of solutions; and an introduction to the solution of partial differential equations by finite differences. Other topics might include finite element or boundary element methods, Galerkin methods, collocation, or variational methods. (Prerequisites: Graduate or undergraduate numerical analysis. Knowledge of a higher level programming language is assumed.)

MA 514. Numerical Linear Algebra

This course provides students with the skills necessary to develop, analyze, and implement computational methods in linear algebra. The central topics include vector and matrix algebra, vector and matrix norms, the singular value decomposition, the LU and QR decompositions, Householder transformations and Given rotations, and iterative methods for solving linear systems, including Jacobi, Gauss-Seidel, SOR, and conjugate gradient methods; and eigenvalue problems. Applications to such problem areas as least squares and optimization will be discussed. Other topics might include: special linear systems, such as symmetric, positive definite, banded or sparse systems; preconditioning; the Cholesky decomposition; sparse tableau and other least-square methods; or algorithms for parallel architectures. (Prerequisite: Basic knowledge of linear algebra or equivalent background. Knowledge of a higher level programming language is assumed.)

MA 519. Optimization

This course provides a basic foundation for students interested in mathematical programming. This course introduces the concepts of convex analysis, optimality conditions, Lagrangian duality, algorithms for unconstrained and constrained optimization, convergence properties and computational complexity of algorithms. Topics covered include: search methods, Newton's method and steepest descent method, trust region methods, penalty/barrier functions, interior point methods, finite element techniques and applications to special nonlinear programming problems arising such areas as in structural optimization using finite element formulations. May be taught by special arrangement. (Prerequisite: Knowledge of graduate or undergraduate numerical analysis, basic linear algebra and a higher level programming language are assumed.)

MA 525. Optimal Control and Design With Composite Materials I

Modern technology involves a wide application of materials with internal structure adapted to environmental demands. This, the first course in a two semester sequence, will establish a theoretical basis for identifying structures that provide optimal response to prescribed external factors. Material covered will include basics of the calculus of variations: Euler equations, transversality conditions, Weierstrass-Erdmann conditions for corner points, Legendre, Jacobi and Weierstrass conditions, Hamiltonian form of the necessary conditions and Noether's theorem. Pontryagin's maximum principle in its original lumped parameter form will be put forth as well as its distributed parameter extension. Chattering regimes of control and relaxation through composites will be introduced at this point. May be offered by special arrangement.

MA 526. Optimal Control and Design With Composite Materials II

Topics presented will include basics of homogenization theory. Bounds on the effective properties of composites will be established using the translation method and Hashin-Shtrikman variational principles. The course concludes with a number of examples demonstrating the use of the theory in producing optimal structural designs. The methodology given in this course turns the problem of optimal design into a problem of rigorous mathematics. This course can be taken independently or as the sequel to MA 525.

MA 530. Discrete Mathematics/CS 501 Discrete Structures

This course provides the student of mathematics or computer science with an overview of discrete structures and their applications, as well as the basic methods and proof techniques in combinatorics. Topics covered include sets, relations, posets, enumeration, graphs, digraphs, monoids, groups, discrete probability theory and propositional calculus. (Prerequisites: College math at least through calculus. Experience with recursive programming is helpful, but not required.)

MA 533. Discrete Mathematics II

This course is designed to provide an in-depth study of some topics in combinatorial mathematics and discrete optimization. Topics may vary from year to year. Topics covered include, as time permits, partially ordered sets, lattices, matroids, matching theory, Ramsey theory, discrete programming problems, computational complexity of algorithms, branch and bound methods.

MA 540/4631. Probability and Mathematical Statistics I

Intended for advanced undergraduates and beginning graduate students in the mathematical sciences and for others intending to pursue the mathematical study of probability and statistics. This course begins by covering the material of MA 3613 at a more advanced level. Additional topics covered are: one-to-one and many-to-one transformations of random variables; sampling distributions, order statistics, and limit theorems. (Prerequisite: A knowledge of MA 3613 and MA 3831/3832 is assumed.)

MA 541/4632. Probability and Mathematical Statistics II

This course is designed to provide background in principles of statistics. Topics covered include: point and interval estimation; sufficiency, completeness, efficiency, consistency; the Rao-Blackwell theorem and the Cramer-Rao bound; minimum variance unbiased estimators, maximum likelihood estimators and Bayes estimators; tests of hypotheses including uniformly most powerful, likelihood ratio, minimax and Bayesian tests. (Prerequisite: A knowledge of MA 540 is assumed.)

MA 542. Applied Regression Analysis

Regression analysis is a statistical tool that utilizes the relation between a response variable and one or more predictor variables for the purposes of description, prediction and/or control. Successful use of regression analysis requires an appreciation of both the theory and the practical problems that often arise when the technique is employed with real-world data. The widespread availability of computers and software has contributed greatly to the expanding use of regression in scientific and industrial work. Topics will be selected from: simple linear regression and correlation; measures of model adequacy; simultaneous inferences; multiple regression; polynomial regression; indicator variables; variable selection and model building; multicollinearity and influential observations; generalized and weighted least squares and robust regression; non-linear regression; and validation of regression models. Application of theory to real-world problems will be emphasized using statistical computer packages. (Prerequisite: A knowledge of statistics at the level of MA 2611 is assumed.)

MA 544. Statistical Response Surface Analysis

Response surface methodology is a collection of statistical techniques for analyzing the relationship between a set of independent variables or operating conditions and a response variable. It is commonly used in scientific and industrial work to (1) describe and explain this relationship; (2) choose operating conditions to achieve desired specification; (3) search for optimal operating conditions. Topics covered include: review of basic probability and statistics, least squares, response surface designs, steepest ascent, and the fitting and analysis of second order models. As time permits, additional topics will be chosen from transformations, ridge systems, and variance-optimal designs. Emphasis will be on the application of the theory to real data using statistical computer packages. (Prerequisite: A knowledge of statistics at the level of MA 2611 is assumed.)

MA 546. The Statistical Design and Analysis of Scientific and Industrial Experiments

The goal of the statistical design and analysis of experiments is to (1) Identify the factors which most affect a given process or phenomenon; (2) Identify the ways in which these factors affect the process or phenomenon, both individually and in combination; (3) Accomplish (1) and (2) with minimum cost and maximum efficiency while maintaining the validity of the results. Topics covered include, as time permits, the implementation and analysis of completely randomized, randomized complete block, nested and nested factorial, split plot type, Latin square type, and other incomplete block designs, factorial designs, and fractional factorial designs and their relation to the Taguchi methodology. Emphasis will be on the application of the theory to real data using statistical computer packages. (Prerequisite: A knowledge of basic statistics at the level of MA 2611 is assumed.)

MA 548. Reliability and Quality Control

This course provides the student with the basic statistical tools needed to (1) evaluate the quality and reliability of manufactured products, and (2) design products and production processes to insure a desired level of quality and reliability. Topics covered include: the philosophy and implementation of continuous quality improvement methods, acceptance sampling, control charts, cumulative sum charts, reliability models, censoring, the identification and fitting of reliability models to data, inference from reliability models. Special emphasis will be placed on realistic applications of the theory using statistical computer packages available. (Prerequisite: A knowledge of basic probability and statistics, at the level of MA 2611 is assumed.)

MA 550. Time Series Analysis and Forecasting

Time series are collections of observations made sequentially in time. Examples occur in a variety of fields, ranging from economics to engineering, and methods of analyzing time series constitute an important area of statistics. There are several objectives in analyzing a time series which can be classified as description, explanation, prediction and control. This course provides students with the basic knowledge of time series both in the frequency domain and in the time domain. Topics covered include, as time permits, autocorrelation; elements of spectral analysis; ARMA models; ARIMA models; Box-Jenkins methodology; fitting; forecasting; seasonal adjustment. Additional topics will be chosen from: Kalman filter; exponential smoothing; Holt-Winters procedures. Applications of the theory to real data using statistical computer packages will be emphasized. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 552. Nonparametric and Robust Statistical Methods

Nonparametric statistical methods do not require modeling a population in terms of a specific parametric family of distributions. Robust statistical methods are methods which retain much of the sensitivity of parametric methods when model assumptions are satisfied but which are relatively insensitive to departures from these assumptions. Topics covered include, as time permits, order statistics and ranks; distribution free tests and associated interval and point estimators including the sign test, rank sum tests, Mann-Whitney-Wilcoxon tests and Kruskal-Wallis tests; the Kolmogorov-Smirnov test; permutation methods; M, L and R estimation and applications; computer techniques and programs; discussion and comparison with standard parametric methods. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 554. Multivariate Analysis

This course is an introduction to statistical methods for analyzing multivariate data. Topics covered are multivariate sampling distributions, tests and estimation of multivariate normal parameters, multivariate ANOVA, correlation and regression, discriminant analysis, factor analysis and principal components. Additional topics covered as time permits include multivariate discrete analysis: loglinear and logit regression models. Students will be required to analyze real data using one of the standard packages available. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 556. Decision Theory and Applied Bayesian Statistics

This course is an introduction to Decision Theory and Applied Bayesian Statistics. Decision theory is concerned with the ways that data can be used to make decisions. The Bayesian approach allows the synthesis of current data with past information to aid decision making. Topics covered include decision theory, Bayes estimation and hypothesis-testing. Standard normal-theory inference problems such as K-sample problems, regression and one-way ANOVA are emphasized. Numerical computation of posterior densities, e.g., Hermite, Laplace approximation and Monte Carlo integration, is also covered. Applications of decision-theoretic and Bayesian methods to such areas as survey sampling theory, reliability theory, time series analysis and categorical data analysis will be discussed. (Prerequisite: A knowledge of MA 541 is assumed or may be taken concurrently.)

MA 558. Statistical Consulting

After suitable preparation through readings and practice consulting sessions, the student will serve as a statistical consultant, under the supervision of statistics faculty, to clients from academia, business and industry. There are no formal prerequisites, but knowledge of a range of statistical methodology will be required for admission.

MA 560. Graduate Seminar

0 credits

Designed to introduce graduate students to study of original papers and afford them opportunity to give account of their work by talks in the seminar.

MA 590. Special Topics

Courses on special topics are offered under this number. Contact the Mathematical Sciences Department for current offerings.

MA 595. Independent Study

1 to 3 credits

Supervised independent study of a topic of mutual interest to the instructor and the student.

MA 599. Thesis

1 or more credits

Research study at the master's level.

MATHEMATICS FOR EDUCATORS

MME 518. Geometrical Concepts

This course focuses primarily on the foundations and applications of Euclidean and non-Euclidean geometries. The rich and diverse nature of the subject also implies the need to explore other topics; for example, chaos and fractals. The course incorporates collaborative learning and the investigation of ideas through group projects. Possible topics include geometrical software and computer graphics, tiling and tessellations, two- and three-dimensional geometry, inversive geometry, graphical representations of functions, model construction, fundamental relationship between algebra and geometry, applications of geometry, geometry transformations and projective geometry, and convexity.

MME 522. Applications of Calculus

2 credits

There are three major goals for this course: to establish the underlying principles of calculus, to reinforce students' calculus skills through investigation of applications involving those skills, and to give students the opportunity to develop projects and laboratory assignments for use by first-year calculus students. The course will focus heavily on the use of technology to solve problems involving applications of calculus concepts. In addition, MME students will be expected to master the mathematical rigor of these calculus concepts so that they will be better prepared to develop their own projects and laboratory assignments. For example, if an MME student chose to develop a lab on convergence of sequence, he/she would be expected to understand the rigorous definition of convergence and how to apply it to gain sufficient and/or necessary conditions for convergence. The process of developing these first-year calculus assignments will enable the MME students to increase their own math-ematical understanding of concepts while learning to handle mathematical and computer issues which will be encountered by their own calculus students. Their understanding of the concepts and applications of calculus will be further reinforced through computer laboratory assignments and group projects. Applications might include exponential decay of drugs in the body, optimal crankshaft design, population growth, or development of cruise control systems.

MME 523. Analysis With Applications

2 credits

This course introduces students to mathematical analysis and its use in modeling. It will emphasize topics of calculus (including multidimensional) in a rigorous way. These topics will be motivated by their usefulness for understanding concepts of the calculus and for facilitating the solutions of engineering and science problems. Projects involving applications and appropriate use of technology will be an essential part of the course. Topics covered may include: dynamical systems and differential equations, growth and decay, equilibrium, probabilistic dynamics, optimal decisions and reward, applying, building, and validating models, functions on Rn vectors, properties of functions, parametric equations, series, applications such as pendulum problems, electromagnetism, vibrations, electronics, transportation, gravitational fields, and heat loss.

MME 524-25. Probability, Statistics, and Data Analysis I, II

4 credits

This course introduces students to probability, the mathematical description of random phenomena, and to statistics, the science of data. Students in this course will acquire the following knowledge and skills: Probability Models: Mathematical models which are used to describe and predict random phenomena. Students will learn several basic probability models and their uses, and will obtain experience in modeling random phenomena. Data Analysis: The art/science of finding patterns in data and using those patterns to explain the process which produced the data. Students will be able to explore and draw conclusions about data using computational and graphical methods. The iterative nature of statistical exploration will be emphasized. Statistical Inference and Modeling: The use of data sampled from a process and the probability model of that process to draw conclusions about the process. Students will attain proficiency in selecting, fitting and criticizing models and in drawing inference from data. Design of Experiments and Sampling Studies: The proper way to design experiments and sampling studies so that statistically valid inferences can be drawn. Special attention will be given to the role of experiments and sampling studies in scientific investigation. Through lab and project work, students will obtain practical skills in designing and analyzing studies and experiments. Course topics will be motivated whenever possible by applications and reinforced by experimental and computer lab experiences. One in-depth project per semester involving design, data collection and statistical or probabilistic analysis will serve to integrate and consolidate student skills and understanding. Students will be expected to learn and use a statistical computer package, such as MINITAB.

MME 526-27. Linear Models I, II

4 credits

This two-course sequence imparts computational skills, particularly those involving matrices; to deepen understanding of mathematical structure and methods of proof; and to discuss a variety of applications of the material developed, including linear optimization. Topics in this sequence may include systems of linear equations, vector spaces, linear independence, bases, linear transformations, determinants, eigenvalues and eigenvectors, systems of linear inequalities, linear programming problems, basic solutions, duality, and game theory. Applications may include economic models, computer graphics, least squares approximation, systems of differential equations, graphs and networks, and Markov processes.

MME 528. Mathematical Modeling and Problem Solving

2 credits

This course introduces students to the process of developing mathematical models as a means for solving real problems. The course will encompass several different modeling situations that utilize a variety of mathematical topics. The mathematical fundamentals of these topics will be discussed, but with continued reference to their use in finding the solutions to problems. Problems to be covered include balance in small group behavior, traffic flow, air pollution flow, group decision making, transportation, assignment, project planning and the critical path method, genetics, inventory control, and queuing.

MME 529. Numbers, Polynomials, and Algebraic Structures

2 credits

This course enables secondary mathematics teachers to see how commonly taught topics such as number systems and polynomials fit into the broader context of algebra. The course will begin with treatment of arithmetic, working through Euclid's algorithm and its applications, the fundamental theorem of arithmetic and its applications, multiplicative functions, the Chinese remainder theorem, and the arithmetic of Z/n. This information will be carried over to polynomials in one variable over the rational and real numbers, culminating in the construction of root fields for polynomials via quotients of polynomial rings. Arithmetic in the Gaussian integers and the integers in various other quadratic fields (especially the field of cube roots of unity) will be explored through applications such as the generation of Pythagorean triples and solutions to other Diophantine equations (like finding integer-sided triangles with a 60 degree angle). The course will then explore cyclotomy, and the arithmetic in rings of cyclotomic integers. This will culminate in Gauss' construction of the regular 5-gon and 17-gon and the impossibility of constructing a 9-gon or trisecting a 60 degree angle. Finally, solutions of cubics and quartics by radicals will be studied. All topics will be based on the analysis of explicit calculations with (generalized) numbers. The proposed curriculum covers topics that are part of the folklore for high school mathematics (the impossibility of certain ruler and compass constructions), but that many teachers know only as facts. There are also many applications of the ideas that will allow the teachers to use results and ideas from abstract algebra to construct problems for their students that have manageable solutions.

MME 531. Discrete Mathematics

This course deals with concepts and methods which emphasize the discrete nature in many problems and structures. The rapid growth of this branch of mathematics has been inspired by its wide range of applicability to diverse fields such as computer science, management, and biology. The essential ingredients of the course are:

Combinatorics:

The Art of Counting

Topics include basic counting principles and methods such as recurrence relations, generating functions, the inclusion-exclusion principle, and the pigeon-hole principle. Applications may include block designs, latin squares, finite projective planes, coding theory, optimization, and algorithmic analysis.

Graph Theory

This includes direct graphs and networks. Among the parameters to be examined are traversibility, connectivity, planarity, duality, and colorability.

MME 562. Seminar: Issues in Mathematics

2 credits

This course gives students an opportunity to participate in focused discussions on various topics in mathematics and mathematics education. Students will research current literature in mathematics and mathematics education. Invited speakers will address issues relevant to a broad understanding of mathematics and its applications in our society. Students will be required to synthesize and critique course materials through written papers and formal presentations. The course will emphasize teachers as professionals and educational innovators. The content of the course will vary depending on the interests of the participants. However, topics may include careers in mathematics; mathematics in industry; historical perspectives and the motivation of mathematical development; critical thinking skills; impact of the NCTM curriculum and evaluation standards; mathematics on the national scene, including the roles of MSEB, NSF, NCTM, AMS, MAA, AMATYC; mathematics reform: then and now; mathematics anxiety; issues in the teaching of developmental mathematics; women and minorities in mathematics; technical writing in mathematics; funding sources for mathematics reform; and assessment in mathematics, including the SAT, the AP Calculus Exam, and ideas on alternative forms of assessment; textbooks and other resources in mathematics.

MME 592. Project Preparation

(Part of a 3-course sequence with MME 594 and MME 596)

2 credits

Students will research and develop a mathematical topic or pedagogical technique. The project will typically lead to classroom implementation; however, a project involving mathematical research at an appropriate level of rigor will also be acceptable. Preparation will be completed in conjunction with at least one faculty member from the Mathematical Sciences Department and will include exhaustive research on the proposed topic. The course will result in a detailed proposal that will be presented to the MME Project Committee for approval; continuation with the project is contingent upon this approval.

MME 594. Project Implementation

2 credits

Students will implement and carry out the project developed during the Project Preparation course. Periodic contact and/or observations will be made by the project advisor (see Project Preparation) in order to provide feedback and to ensure completion of the proposed task. Data for the purpose of evaluation will be collected by the students throughout the term, when appropriate. If the project includes classroom implementation, the experiment will last for the duration of a semester.

MECHANICAL ENGINEERING

Fluids Engineering

ME 511. Incompressible Fluid Dynamics

An introduction to graduate level fluid dynamics including dimensional analysis, Eulerian and Lagrangian descriptions, flowlines, conservation equations, governing equations of viscous fluid motion, exact solutions of Navier-Stokes and Euler equations, unsteady flows, laminar boundary layer theory, turbulence, separation., Stokes flow, vorticity dynamics, potential flow, and surface flows.
(Prerequisites: Fundamentals of thermodynamics and mechanics, knowlege of advanced mathematics, undergraduate courses in fluid mechanics.)

ME 512. Gas Dynamics and Real Gas Effects

Kinetic theory of gases including equilibrium and non-equilibrium gas properties, macroscopic equations, binary and inelastic collisions, chemical reactions. Equilibrium flows including steady and unsteady shock waves, nozzle flow, Prandtl-Meyer flow, theory of characteristics, effects of head addition and friction, linearized compressible flow and acoustics. Compressible flows with vibrational, chemical or translational nonequilibrium including variable transport properties, nozzle flow, and shock waves.
(Prerequisites: Background in fluid dynamics (incompressible and compressible), thermodynamics and basic undergraduate physics and chemistry.)

ME 513. Thermodynamics

Review of the zeroth, first and second laws of thermodynamics and systems control volume. Applications of the laws to heat engines and their implications regarding the properties of materials. Equations of state and introduction to chemical thermodynamics.

ME 515. Computational Methods for PDEs in Engineering Science

This course is devoted to the numerical solution of partial differential equations encountered in Engineering Sciences. Finite difference and finite element methods are introduced and developed in a logical progression of complexity. These numerical strategies are used to solve actual problems in heat flow, diffusion, wave propagation, vibrations, fluid mechanics, hydrology and solid mechanics. Weekly computer exercises are required to illustrate the concepts discussed in class.

ME 516. Heat Transfer

Review of governing differential equations and boundary conditions for heat transfer analysis. Multi-dimensional and unsteady conduction, including effects of variable material properties. Analytical and numerical solution methods. Forced and free convection with laminar and turbulent flow in internal and external flows. Characteristics of radiant energy spectra and radiative properties of surfaces. Radiative heat transfer in absorbing and emitting media. Systems with combined conduction, convection, and radiation. Condensation, evaporation, and boiling phenomena. (Prerequisite: Background in thermodynamics, fluid dynamics, ordinary and partial differential equations, and basic undergraduate physics.)

ME 611. Turbulence

Material to be covered: Introduction and motivation, statistical techniques for analysis, mean flow dynamics (Reynolds decomposition), Kolmogorov's theory, instrumentation, classical turbulent flows: shear layers, jets, wakes, boundary layers, and pipe flow. (Prerequisites: Fundamentals of mechanics and thermodynamics, graduate level course in fluid mechanics, and knowledge of advanced mathematics.)

ME 612. Computational Fluid Dynamics

Computional methods for incompressible and compressible viscous flows. Navier Stokes equations in general coordinates and grid generation techniques. Finite volume techniques including discretization, stability analysis, artificial viscosity, explicit and implicit methods, flux-vector splitting, TVD schemes, and multi grid methods. Finite elements. Concepts of vectorization and parallel computing. Applications are drawn from internal, external flows, materials processing. (Prerequisite: Fluid dynamics and introductory course in numerical methods.)

ME 613. Transport Phenomena

Conservation laws, with an emphasis on the similarities between the different mechanisms for the transport of heat, mass, and momentum. Theory of molecular transport. Diffusion phenomena in stationary, flowing, and unsteady processes. Mass diffusion in chemically reacting, multi-phase, and multicomponent systems. Computational techniques. Selected special topics and applications may include turbulent convective flows, combustion, and materials processing.

Dynamics and Controls

ME 522 Mechanical Vibrations

Vibration analysis for both discrete and continuous linear systems. Start with an enhanced review of the fundamentals of single-degree-of-freedom vibration analysis. Both Newton-D'Alembert's vectorial approach and Lagrangian equations are discussed. General properties of related stiffness, mass, and damping matrices are addressed. Modal analysis for linear systems are emphasized. Computational methods in vibration analysis are introduced. Applications include vehicles traveling on a rough surface, and multi-story buildings subjected to seismic and wind loading, and vibration analysis of bars, beams and plates.

ME 523 Applied Linear Control

Modeling of complex systems used in various areas of engineering. Analytical description of dynamic physical systems, time and frequency domain representations. System characteristics such as controllability, observability and stability. Design of feedback controllers using state-space methods including pole placement and optimal control. State observers and introduction to Kalman filters. Performance limitation of control systems and trade-offs in control design. Design of control synthesis is performed using Matlab/Simulink. Term projects focus on design, analysis and implementation of current engineering control problems. (Prerequisites: Differential equation and fundamentals of linear algebra.)

ME 527. Dynamics

Basic concepts and general principles of classical kinematics and dynamics of particles, system of particles, rigid and deformable bodies are presented. Particle motion along arbitrary trajectories is discussed in general coordinate systems. The governing equations of motion are derived by both Newton-D'Alembert's vectorial approach and Lagrange-Hamilton's variational approach. Applications include central-force orbital motion, binary collisions, motion in noninertial reference frames, rigid body motion, vibration of continuous systems, and dynamic stability.

ME 621. Dynamics and Signal Analysis

A laboratory-based course which applies Fourier and cepstral signal analysis techniques to mechanical engineering problems. The theory and application of the Fourier series, Fast Fourier Transform (FFT) and the cepstrum to the analysis of mechanical and acoustical systems is presented. Digital sampling theory, windowing, aliasing, filtering, noise averaging and deconvolution are discussed. Limitation of, and errors in, implementation of these techniques are demonstrated. Students will perform weekly experiments in the Structural Dynamics and Vibration Laboratory, which reinforce the theories presented in lectures. Application will include structures, acoustics, rotating machinery and cams.

ME 622. Advanced Dynamics and Vibrations

The course presents advanced topics in dynamics and vibrations of machines and structures. Depending of the instructor, the course will include a selection of the following topics: extended discussion of vibration analysis of linear systems with distributed parameters, an introduction to vibration of nonlinear systems, numerical methods for vibration analysis, random vibrations, stability of dynamic systems, flow induced vibrations, and rotordynamics.

ME 623. Applied Non-linear Control
Introduction to the analysis and design of non-linear control systems. Stability analysis using Lyapunov, input-output and asymptotic methods. Design of stabilizing controllers using a variety of methods: linearization, absolute stability, sliding modes, adaptive, and feedback linearization. Applications include control design for robot systems (postion and trajectory control), flexible structures (vibration control), spacecraft attitude control, manufacturing systems. Case studies for systems with smart actuators/sensors (Piezo, SMA, Magnetrostrictive), deadzones and hysteresis, etc. Design of control synthesis is performed using Matlab/Simulink. Term projects will focus on design, analysis and implementation of current engineering control problems. (Prerequisites: Differential equations and fundamentals of linear algebra.)

ME 624. Random Vibration and Mechanical Signature Analysis
Probabilistic methods in dynamics are described, as they are used to predict systems' response to highly irregular, or random loadings, such as that of civil engineering structures to earthquakes, of aircraft structures to turbulent gusts and of ships and off-shore structures to ocean waves. Applications of random vibration analyses for reliability predictions and for mechanical signature analysis (MSA) will be illustrated, where MSA means on-line condition monitoring for an operating machine or structure by using proper processing of its measured response signal. The course contains brief introduction into theory of probability and theory of random processes, which makes it self-contained.

Structures and Materials

ME 531. Applied Elasticity
This course is intended for students with undergraduate backgrounds in mechanics of materials. It includes two- and three-dimensional states of stress, linear and non-linear measures of strain, and generalized Hooke's Law. Also covered are exact solutions for bending and torsion; thick walled pressure vessels, rotating disks, stress functions for two- and three-dimensional problems and bending and torsion of unsymmetric beams.

ME 532. Continuum Mechanics
Emphasis on the distinction between general principles that apply to all deforming materials and the specific constitutive assumptions that are made when modeling material behavior. The course includes a brief review of the necessary mathematics and then proceeds to the kinematics of deformable media, the concepts of stress and stress transformations, and the general balance laws. The remainder of the course deals with general constitutive theory and constitutive relations for selected materials that have relevance to structural, fluid dynamics, materials processing and materials handling.

ME 533/CE 524. Finite Element Method and Applications
This course serves as an introduction to the basic theory of the finite element method. Topics covered include matrix structural analysis variation form of differential equations, Ritz and weighted residual approximations, and development of the discretized domain solution. Techniques are developed in detail for the one- and two-dimensional equilibrium problem. Examples focus on elasticity and heat flow with reference to broader applications. Students are supplied microcomputer programs amd gain experience in solving real problems. (Prerequisites: Elementary differential equations, solid mechanics and heat flow.)

ME 534. Laser Engineering Science and Applications
In this course, a unified account of the present-day knowledge of lasers and their applications in varied professional and industrial fields will be given through a series of in-class lectures and laboratory demonstration. Special attention will be given to factors that must be evaluated when a laser system is being devised for a specific application. Course coverage will include: types of lasers and their characteristics, shaping of laser beams, measurement of laser beam parameters, transmission of laser beams, interaction of laser beams with materials, mathematical modeling of laser processes, laser processing of materials, fiber-optic applications of lasers, laser metrology, and related topics.

ME 535/MTE 582. Mechanical Behavior of Materials
Theory of strenghtening mechanisms with emphasis on dislocation theory for single and multiphase alloys and composite structures. Application of theory to produce engineered structures. (Prerequisites: ME 3823 and ME 4840 or equivalent)

ME 631. Advanced Mechanics of Solids
This course is a continuation of ME 531. Depending on the instructor, it will include a selection of the following topics: exact solutions for three-dimensional problems using vector potentials, Hertz contact solution, energy methods, elastic stability, an overview of plates and shells, and an introduction to plasticity and viscoelasticity theory.

ME 632. Dynamics of Composite Structures
The course covers topics related to dynamics of composite structures, including introduction to composite materials, fiber reinforced composites, governing equations of motion of composite beams, plates and shells, vibration of thick composite plates and shell, and response of composite structures due to impact.

ME 633/CE 526. Advanced Finite Element Methods
Second course in the theory of the finite element method. Topics to be covered include alternate variational methods for formulating the finite element equations; methods for treating material and geometric nonlinearities; methods for transient analysis; plate and shell analysis; and an introduction to the boundary element method. (Prerequisite: ME 533. Helpful, but not mandatory to have a background in elasticity, dynamics and vibrations.)

ME 634. Holographic Numerical Analysis
Recent advances in holographic analysis of body deformations are discussed. Included in the course are topics covering sandwich holography, opto-electronic fringe interpolation technique, theory of fringe localization, use of projection matrices and the fringe tensor theory of holographic strain analysis. The application of interactive computer programs for holographic analysis of engineering and biological systems will be outlined. Lectures are supplemented by laboratory demonstrations and experiments. (Prerequisites: Matrix algebra, vector calculus, and consent of instructor.)

Manufacturing and Design

ME 542/MFE 510. Control and Monitoring of Manufacturing Processes

Covers a broad range of topics centered on control and monitoring functions for manufacturing, including process control, feedback systems, data collection and analysis, scheduling, machine-computer interfacing, and distributed control. Typical applications are considered with lab work.

ME 543/MFE 520. Design and Analysis of Manufacturing Processes

The first half of the course covers the axiomatic design method, applied to simultaneous product and process design for concurrent engineering, with the emphasis on process and manufacturing tool design. Basic design principles as well as qualitative and quantitative methods of analysis of designs are developed. The second half of the course addresses methods of engineering analysis of manufacturing processes, to support machine tool and process design. Basic types of engineering analysis are applied to manufacturing situations, including elasticity, plasticity, heat transfer, mechanics and cost analysis. Special attention will be given to the mechanics of machining (traditional, non-traditional and grinding) and the production of surfaces. Students, with the advice and consent of the professor, select the topic for their term project.

ME 544/MFE 530. Computer-Integrated Manufacturing

An overview of computer-integrated manufacturing (CIM). As the CIM concept attempts to integrate all of the business and engineering functions of a firm, this course builds on the knowledge of computer-aided design, computer-aided manufacturing, concurrent engineering, management of information systems and operations management to demonstrate the strategic importance of integration.

ME 545. Computer Aided Design and Geometric Modeling

This course covers topics in computer-aided geometric design and applications in mechanical engineering. The objectives of the course are to familiarize the students with complex geometric modeling and analytical techniques used in contemporary computer-aided design systems. Topics to be covered may include complex curve and surface generation, Boolean algebra and solid modeling, transformations, computational and analytic geometry, automatic mesh generation, tool path generation, offsets and intersections of complex shapes, graphics standards and data transfer, rendering techniques, parametric design and geometric optimization, numerical methods for geometric analysis and graphics design programming. (Prerequisites: calculus, linear algebra, computer programming, and some familiarity with a CAD system.)

ME 641. CAM Design

Basic and advanced methods of cam design for high speed production machinery and automotive applications will be addressed. Classical as well as polynomial and spline-based methods will be used to design cm contours. Issues of cam manufacturing and vibrations as related to cam dynamic behavior will be discussed. Practical aspects of cam design will be exercised through projects and laboratory assignments. (Recommended background: Undergraduate level courses in kinematics and vibrations. Familiarity with the techniques of dynamic signal analysis (ME 621) would be helpful.)

Biomechanical Engineering

ME 550. Tissue Engineering

This biomaterials course focuses on the selection, processing, testing and performance of materials used in biomedical applications with special emphasis upon tissue engineering. Topics include: material selection and processing, mechanisms and kinetics of material degradation, cell-material interactions and interfaces; effect of construct architecture on tissue growth; and transport through engineered tissues. Examples of engineering tissues for replacing cartilage, bone, tendons, ligaments, skin and liver will be presented. (Recommended preparation: A first course in biomaterials equivalent to ME/BE 4814 and a basic understanding of physiology and cell biology.)

ME 552. Tissue Mechanics

This biomechanics course focuses on advanced techniques for the characterization of the structure and function of hard and soft tissues and their relationship to physiological processes. Applications include: tissue injury, wound healing, the effect of pathological conditions upon tissue properties and design of medical devices and prostheses. (Recommended preparation: A first course in biomechanics equivalent to ME/BE 4504.)

ME 554. Composites with Biomedical and Materials Applications

Introduction to fiber/particulate reinforced, engineered and biologic materials. This course focuses on the elastic description and application of materials that are made up of a combination of submaterials, i.e., composites. Emphasis will be placed on the development of constitutive equations that define mechanical behavior of a number of applications including: biomaterial, tissue, and material science. (Prerequisites: understanding of stress analysis and basic continuum mechanics.)

ME 558. Biofluids and Biotransport

The emphasis of this course is on modeling fluid flow within the cardiovascular and pulmonary systems and the transport processes that take place in these systems. Applications include artificial heart valves, atherosclerosis, arterial impedance matching, clinical diagnosis, respiration, aerosol and particle deposition. Depending upon class interest, additional topics may include: reproductive fluids, animal propulsion in air and water and viscoelastic testing. (Recommended preparation: A first course in biofluids equivalent to ME/BE 4506.)

Other Activities

ME 591. Graduate Seminar

Seminars on current issues related to various areas of mechanical engineering are presented by authorities in their fields. All full-time mechanical engineering students are required to register. (No credit)

ME 593. Special Topics

Arranged by individual faculty with special expertise, these courses survey fundamentals in areas that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Graduate Office well in advance of the offering. (Prerequisite: Consent of instructor)

ME 598. Directed Research

For M. Eng. students wishing to gain research experience, for M.S. students wishing to gain research experience peripheral to their thesis topic, or for doctoral students wishing to obtain research credit prior to admission to candidacy. (Prerequisite: Consent of Thesis Advisor)

ME 599. Thesis Research

For master's students wishing to obtain research credit toward their thesis. (Prerequisite: Consent of Thesis Advisor)

ME 693. Advanced Special Topics

Arranged by individual faculty with special expertise, these courses cover advanced topics that are not covered by the regular mechanical engineering course offerings. Exact course descriptions are disseminated by the Mechanical Engineering Graduate Office well in advance of the offering. (Prerequisite: Consent of instructor)

ME 698. Pre-dissertation Research

Intended for doctoral students wishing to obtain research credit prior to admission to candidacy. (Prerequisite: Consent of Dissertation Advisor)

ME 699. Dissertation Research

Intended for doctoral students admitted to candidacy wishing to obtain research credit toward their dissertations. (Prerequisite: Consent of Dissertation Advisor)

PHYSICS

PH 501. Mathematical Methods of Physics I

Vector calculus, special functions, calculus of variations, linear transformation theory, Green's functions, complex variables and integral equations. Course may be offered by special arrangement.

PH 502. Mathematical Methods of Physics II

Probability theory, harmonic analysis, integral equations, and functions of a complex variable. Course may be offered by special arrangement.

PH 503. Group Theory

Theory of group representations; point groups and continuous groups of physical interest; applications to molecular vibrations, crystal properties, quantum mechanics and particle physics. Course may be offered by special arrangement.

PH 511. Classical Mechanics

Lagrangian and Hamiltonian formulations. Rigid body motion. Poisson brackets, Hamilton-Jacobi theory. (Prerequisite: B.S. in physics or equivalent.)

PH 514. Quantum Mechanics I

Schrodinger wave equation, potential wells and barriers, harmonic oscillator, hydrogen atom, angular momentum and spin. (Prerequisite: B.S. in physics or equivalent.)

PH 515. Quantum Mechanics II

Perturbation theory, scattering theory, Born approximation, quantum theory of radiation, the Dirac equation. (Prerequisite: PH 514.)

PH 522. Thermodynamics and Statistical Mechanics

Ensemble theory; canonical, microcanonical and grand canonical ensembles. Quantum statistical mechanics; Bose-Einstein and Fermi-Dirac statistics. (Prerequisite: PH 511.)

PH 533. Advanced Electromagnetic Theory

Classical electrodynamics including boundary-value problems using Green's functions. Maxwell's equations, electromagnetic properties of matter, wave propagation and radiation theory. (Prerequisite: B.S. in physics or equivalent.)

PH 542. Modern Optics

Geometrical optics, scalar diffraction theory, coherence and Fourier optics. Holography and laser physics.

PH 554. Solid State Physics

Phonons and specific heat of solids; electronic conductivity and band theory of solids; Fermi and Bose gases; magnetic interactions. (Prerequisite: PH 514.)

PH 597. Special Topics

credits as arranged

Title of recently offered courses include Superlattices and Semiconductor Heterostructures; Numerical Methods in Physics; Topics in 20th Century Physics; Excitations and Wave Interactions and Wave Interactions in Crystals.

PH 597P. Special Topics: Photonics

Fiber optics, lasers, light emitting diodes, photodetectors, planar optical waveguides, fiber lasers and fiber amplifiers. (Prerequisite: a B.S. degree in physics or equivalent.)

PH 616. Quantum Mechanics III

Quantum theory of radiation and introduction to quantum field theory. Course may be offered by special arrangement.(Prerequisite: PH 515.)

PH 634. Electrodynamics

Classical electron theory, retarded potentials, radiation. Course may be offered by special arrangement. (Prerequisite: PH 533.)

PH 644. Seminar in the Interaction of Radiation and Matter

Quantum theory of radiation, interacting systems, magnetic resonance, laser models and relaxation phenomena. Course may be offered by special arrangement.

PH 656. Quantum Theory of Solids

Advanced topics in the quantum theory of solids. Course may be offered by special arrangement.(Prerequisite: PH 554.)

Directed Research

varies

A directed and coherent program of research that, in most cases, will eventually lead to thesis or dissertation research.

M.S. Thesis Research

varies

Each student will work under the supervision of a member of the department on an experimental or theoretical problem.

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