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. Dilorio, 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

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, downstream 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 mentorship and 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 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 absence 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 GPA 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 biortransport 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 vasculature 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 of Colorado
P. C. Pedersen, Professor of Electrical and Computer Engineering; Ph.D., University of Maryland
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; Ph.D., 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. (Looff)

Biomedical Materials


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-Il 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 Physiology; 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 postgraduate experience or a master’s degree are encouraged to apply. Research assistantships 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
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 pharmaceutically 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.

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 pharmaceutically 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.

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 pharmaceutically 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.

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 pharmaceutically 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.
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, UTL 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 is 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 Río 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 required to present as a part of the thesis and

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 strengthens 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.

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.

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 high-way 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 candidate’s 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 interdisciplinary 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 admission 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. Wakesly, 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

**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 525)
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 524)
Advances in Digital Communication (EE 533)
Multiple Processor and Distributed Systems (EE 575/CS 515)
Advanced Operating System Theory (CS 573)
Design of Software Systems (CS 590)
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 535/CS 525W)
Any of the courses EE 535, EE 530/CS 530, 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 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
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 electromagnetic 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 undergraduate 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, mult-ple-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 design & 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/photic 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 electromechanical 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, workstations, 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 Xilinx 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. 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 knowledge 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 dissertation, 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 elec-
trical 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’s degree in electrical and computer engineering may apply for the doctoral program of study. Admission to the Ph.D. program will be based on a review of the application and associated references.

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 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; MG 599 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 100 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 Massachusetts
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)
  MG 511 (3 credits), MG 512 (4 credits), MG 513 (3 credits), MG 514 (4 credits), MG 515 (2 credits)
• 5 Core Courses:
  MG 511 (3 credits), MG 512 (4 credits), MG 513 (3 credits), MG 514 (4 credits), MG 515 (2 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.

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 Mechanical 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 PCs 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 seminars 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 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 metallurgical 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 1700°C 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 facilities are for the study of corrosion, erosion, wear and electrochemistry of materials. Included are potentiostat/galvanostats for experimental control and data collection using and EGGG 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.

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, rheo-casting 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 coop 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/MP.

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, and their performance during processing.

1. The laboratory has joint research programs with the solidification laboratory at MIT and Oak Ridge National Laboratory. The laboratory has also exchanged 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 Bruker 200 MHz 48 Transfourier nuclear magnetic resonance spectroscopy system for proton and 13C 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 JSMB810 (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 computer-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; 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 kilometers (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 ceramc membe.
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 12/20 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 goniometers 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 GPA of 3.0 or higher. Waiver of any of these requirements must be approved by the materials science and engineering graduate committee, which will exercise its discretion in handling any extenuating circumstances or problems.

Examples of Typical 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.


- 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 University
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 mathematical 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 graduate 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 and MA 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 400-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
Mechanical Engineering

Programs of Study
The Mechanical 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 through the computational network and are supported by data acquisition systems, and high speed flow visualization systems are available. Separate areas are provided for model preparation and small-scale experiments.

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 propulsion, 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-pictures 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 acquisition systems, instrumentation for measuring acceleration, velocity, force and pressure, and computer data acquisition 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 acquisition 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 measurements, 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. Aluminum 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:
- 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 Metallurgy, 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), 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, EGM 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, Electromechanical systems

J. J. Rencis, Ph.D. (Case Western Reserve University), Boundary- and Finite-Element Methods, Computational Mechanics

J. M. Sullivan, Jr., D.E. (Thayer School of Engineering, Dartmouth College), Numerical Analysis, Mesh Generation, CAD

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 Materials

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, Magnetogasodynamics, 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, Adaptive Structures

H. Johari, Ph.D. (University of Washington), Experimental Fluid Mechanics, Turbulence, Aerodynamics

M. M. Makhouf, Director of Aluminum Casting Laboratories, MPI, Ph.D., (MPI) 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. Demetrio, Ph.D. (University of Southern California), Systems and Control, Structural/Acoustic Control, Fault Detection/Diagnosis

M. S. Fofana, Ph.D. (University of Waterloo), Axiomatic Design

S. S. Kohles, Ph.D. (University of Wisconsin at Madison), Biomedical and Clinical Engineering

Non Tenure Track

L. Arnber, Adjunct Affiliate Professor, MPI

A. Bratus, Adjunct Professor

E. Cobb, Visiting Assistant Professor, Ph.D. (University of Connecticut), Manufacturing & Design

E. Eckert, Adjunct Affiliate Professor, MPI

V. Entov, Ph.D., Adjunct Professor

B. Ghassemi, Visiting Assistant Professor

P. Grigg, Ph.D., Adjunct Professor

U. Gummesson, 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.

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 a member of the dissertation committee. A student may take the exam no more than twice.

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 dissertation advisor prior to registering for more than 9 credits.

Dissertation Committee: Formed by student prior to registering for more than 18 credits. Consists of 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.
obtained in any other listed courses, then they better in each. If grades of C or lower are (from the submitted list) with grades of B or upon the completion of two graduate courses degrees. However, admission is contingent toward both the undergraduate and graduate is qualified for graduate school, and signifies Acceptance into either the B.S./M.S. or (usually D-term) of the junior year. (including recommendations) should be applicant’s junior year. Ideally, applications are submitted prior to the second half of the courses that the applicant will take in the 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 into 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. Phillips, 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 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, photo-refractive materials, atom pipes.

S. W. Pierson, Statistical mechanics, High-T superconductors, vortices.


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.