Program of Study

The department offers a master of science (M.S.) degree in biology and biotechnology. This degree requires students to successfully complete a set of required "core" courses in the field and a thesis project that applies the basic principles of biology and biotechnology to a current research problem. Graduates with the master of science degree will have a broad knowledge of the field of biology and biotechnology as well as demonstrate detailed knowledge and applied research skills in their area of specialization. Students who complete this M.S. degree program will be well prepared for further graduate education, or for employment in academics or industry.

Faculty in the Biology and Biotechnology Department have research interests in the areas of bioprocessing technology, cell biology, developmental biology, ecology, evolution, environmental biology, molecular genetics, neurobiology, and plant and animal organismal biology. Students seeking the M.S. degree in biology and biotechnology should plan to work directly with one of the department's faculty in his or her research specialty area. The department suggests that, prior to applying for entrance into the M.S. program, students use the information at the department's Web site (http://www.wpi.edu/Academics/Depts/Bio) to help identify potential faculty advisors.

Degree Requirements

For the M.S. in Biology and Biotechnology

As with the standard WPI requirements for the M.S. degree, students pursuing the M.S. degree in biology and biotechnology must complete a minimum of 30 credit hours of course and theses work, six of which must be thesis research credits. In addition, M.S. students must successfully complete (grade of B or higher) three of the four departmental core courses (BB575, BB576, BB577 or BB578) and three credits of seminar (BB501, 1 credit per semester). Students must assemble an Advisory Committee of three faculty members. Two of the committee members must be biology and biotechnology faculty members. One of the biology and biotechnology faculty members will chair the committee and be the student’s faculty advisor. The Advisory Committee must review and approve each M.S. student’s program of study and thesis research.

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 credit minimum
- BB courses at the 4000 or 500 level (an M.S. in a biological field may be considered acceptable)
- 15 credit 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 credit maximum
- At the 4000 level or below for all requirements
- 2 credit minimum
- To meet the cultural studies requirement
- 2 credit minimum
- To meet the cultural studies requirement
- 3 credit minimum
- Biology Seminar (BB 501)
- Required every semester

Teaching Requirement

- 2 credit minimum

The objective of this requirement is formal training in pedagogy. It can be fulfilled by enrolling in: (1) an advanced undergraduate or graduate course in education; or (2) a mentored teaching experience (IS/P) arranged with an individual faculty member, within the major discipline of the student and the professor. This mentored teaching experience is distinguished from a teaching assistantship in that it requires significant mentored student involvement in course development, delivery and evaluation.

Cultural Studies Requirement

- 2 credit 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 under the guidance of a humanities advisor. For example, a student could register for 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, Reports and Dissertation Defense

A Ph.D. qualifying exam is required and should be taken following the first year of study. A majority of the Examining Committee must be members of the biology and biotechnology department faculty. The committee must also approve the student’s dissertation research proposal and will meet each semester to review and assess the student’s progress. Candidates for the Ph.D. degree must also give annual presentations of their research work to the department as part of the graduate seminar course.

A public defense of the completed dissertation is required of all students, and will be followed immediately by a defense before the Examining Committee. All members of the Examining Committee must be present for the defense. Operational details of the program, including the student qualifying exam and dissertation defense, can be found in the graduate handbook provided to all entering students.

For the Ph.D. in Biomedical Science

The department of biology and biotechnology participates in 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. This Consortium program includes...
Biology and Biotechnology

WPI, Clark University, the University of Massachusetts Medical School and the Worcester Foundation for Biomedical Research. Applicants to the program must have a commitment to serve as the student’s Research Advisor from a faculty member at one of the Consortium institutions. Students in the program will receive their Ph.D. from WPI, but may conduct dissertation research at any of the Consortium institutions. Students who enter the program through WPI’s department of biology and biotechnology must satisfy the general degree requirements of the University, and adhere to the rules and regulations for graduate students in the department. A complete description of procedures and degree requirements is available in the department office.

**Faculty**

- **J. Rulfs**, Associate Professor and Department Head; Ph.D., Tufts University
- **D. S. Adams**, Professor; Ph.D., University of Texas at Austin
- **J. C. Bagshaw**, Professor; Ph.D., University of Tennessee
- **R. D. Cheetham**, Professor; Ph.D., Purdue University
- **T. C. Crusberg**, Associate Professor; Ph.D., Clark University
- **A. Dilorio**, Affiliate-Assistant Professor; Ph.D., WPI
- **D. G. Gibson III**, Assistant Professor; Ph.D., Boston University
- **J. E. Miller**, Professor; Ph.D., Case Western Reserve University
- **S. M. Politz**, Associate Professor; Ph.D., University of California at Los Angeles
- **E. Ryder**, Associate Professor; Ph.D., Harvard Medical School
- **J. Tyler**, Assistant Professor; Ph.D., SUNY, Albany
- **P. J. Weathers**, Professor; Ph.D., Michigan State University
Programs of Study
The goal of the biomedical engineering graduate programs 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.

Master’s Degree Programs
There are three master’s degree options in biomedical engineering: the Master of Science (M.S.) in Biomedical Engineering, the Master of Engineering (M.E.) in Clinical Engineering and the Master of Engineering (M.E.) 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 master of engineering in clinical 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.

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
   UMMHC-Memorial Campus and UMMS
2. Cardiovascular Medicine
   UMMS Surgery, UMMS

The master of engineering program is considered to be a terminal professional degree.

Combined B.S./Master’s Degree Program
This program affords an opportunity for outstanding WPI undergraduate students to earn both a B.S. degree and a master’s degree in biomedical engineering concurrently, and in less time than would typically be required to earn each degree separately. The principal advantage of this program is that it allows for certain courses to be counted towards both degree requirements, thereby reducing total class time.

With careful planning and motivation, the Combined Program typically allows a student to complete requirements for both degrees with only one additional year of full-time study (five years total). However, because a student must still satisfy all graduate degree requirements, the actual time spent in the program may be longer than five years. There are two degree options for students in the Combined Program: a thesis-based master of science (B.S./M.S.) option and a non-thesis master of engineering (B.S./M.E.) option.

Doctoral Programs
There are two doctor of philosophy degree 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 Medical School (UMMS). 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 with the growing medical device and biotechnology industry, which have become major economic factors in the Commonwealth of Massachusetts.

The joint WPI/UMMS 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 UMMS, with the appropriate designation on the diploma.

Research Interests

Biomaterials / Tissue Engineering
Research focuses on understanding the interactions between cells and precisely bioengineered scaffolds that modulate cellular functions such as adhesion, migration, proliferation, differentiation and extracellular matrix remodeling.

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

Biomedical Sensors and Bioinstrumentation
The development of integrated biomedical sensors for invasive and noninvasive blood gas and glucose monitoring. Design and in vivo evaluation of reflective pulse oximeter sensors. Microcomputer-based medical instrumentation, fiberoptic sensors for medical instrumentation, application of optics to biomedicine.

The development and testing of various invasive and noninvasive biosensors and associated bioinstrumentation.
Biomedical Engineering

Noninvasive optical sensors for measuring glucose in diabetic individuals, urea in hemodialysis dialysate, other biochemical analyses, as well as reagentless chemistry measurements are being developed. (Peura)

**In Vivo Optical Imaging**

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

**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 metabolite-imaging and spectroscopy techniques for use in the evaluation of treatment of cancer; (2) development of NMR imaging methods to delineate the “area of risk” following stroke and assess potential therapeutic intervention; and (3) development of noninvasive methods for measuring tissue blood flow, as well as tumor oxygenation, to evaluate the response of neoplasms to radiotherapy and chemotherapy. Nonmedical applications include nondestructive testing and characterization of materials using high resolution (“microscopic”) NMR imaging and fluid velocity imaging in hollow-fiber bioreactors. (Sotak, Helmer)

**Soft Tissue Biomechanics/Tissue Engineering**

Research focused on understanding the growth and development of connective tissues and on the influence of mechanical stimulation on cells in native and engineered three-dimensional constructs.

Research areas include: (1) micromechanical characterization of tissues, (2) constitutive modeling, (3) creation of bioartificial tissues *in vitro*, and (4) the effects of mechanical stimulation on the functional properties of cells and tissues. (Billiar)

**Bacterial Adhesion to Biomaterials**

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

**Biomechanics**

Research involving the relationship between the applied stress and the response of neurons located in soft tissues is being conducted at the University of Massachusetts Medical School. Collaborative orthopedic research on large and small animals is being conducted at Tufts University School of Veterinary Medicine. 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 related to arterial stenosis and the influence of atherosclerosis on vasculature and dynamic aortic compliance are being investigated. Additional studies include evaluation of osteoarthritis and osteoporosis models, and interfacial problems associated with engineered biomaterials. (Hoffman, Savilonis)

**Biomedical Materials**


**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, Glick, Davis)

**Magnetic Resonance Imaging and Spectroscopy of Brain Function**

The development and application of magnetic resonance imaging (MRI) and spectroscopy (MRS) to the study of brain function in animal models, including: (1) novel methodologies to dynamically measure cerebral blood flow, BOLD (vascular oxygenation), compartment-specific tissue oxygen tension, arterial and venous blood volume fractions; (2) high-resolution functional MRI techniques; and (3) simultaneous electrophysiological and functional MRI recordings. Applications include: (1) the neurophysiological and biophysical basis of functional MRI signal sources; (2) submillimeter columnar structures and organization; (3) blood flow, oxygenation and function of the retina; and (4) functional recovery and reorganization after stroke. (Duong)

**Sensory and Physiologic Signal Processing**

Application of signal processing, mathematical modeling and other electrical and computer engineering skills to the study of issues related to human sensation and physiology. Major areas of focus are hearing and electromyography (EMG). Hearing research is concentrating on improved signal processing in hearing aid devices to improve speech perception by the hearing impaired. In the area of EMG (the electrical activity of skeletal muscle),
Research Laboratories and Facilities
Research projects are primarily conducted in WPI’s Salisbury Laboratories and on the UMMS campus. Core WPI biomedical engineering research laboratories include a bioinstrumentation laboratory, a biomedical/materials/tissue engineering laboratory, a biosensor research laboratory, an optical imaging laboratory and a soft tissue biomechanics/tissue engineering laboratory. Other research projects are conducted in the laboratories of associated biomedical engineering program faculty at WPI and UMMS. Major areas of research focus in these laboratories include biomechanics, biological signal processing, imaging, tissue engineering and ultrasound. A close cooperation with the Tufts University School of Veterinary Medicine makes their staff and facilities available for project work and internships.

A Nuclear Magnetic Resonance (NMR) imaging facility is located at the Central Massachusetts Magnetic Imaging Center (CMMIC) and is part of a joint research program between the Department of Biomedical Engineering and the Department of Radiology at the UMass Memorial HealthCare (UMMHC) Center. This 1630-square-foot research facility houses a General Electric (GE) CSI-II 2.0 Tesla (T) / 45 cm imaging spectrometer as well as a chemistry/electronics laboratory for sample preparation and radio frequency coil research. In addition to the research facility, an 8500-square-foot clinical MR facility housing two GE 1.5 T clinical imaging instruments is available at the CMMIC for suitable research projects.

In addition to the above research laboratories, the department maintains a number of teaching laboratories and facilities that may support research activities, including a bioinstrumentation and biosignals laboratory, a computing and imaging facility, a dedicated projects laboratory and a physiology teaching facility. The department of biology and biotechnology, also located in the Salisbury Laboratories, maintains a number of facilities that also may support biomedical engineering research activities. The WPI Gordon Library provides complete library services. Access to other libraries in the Worcester area, including the UMMS medical library, is available.

Degree Requirements
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, biomedical engineering, or equivalent course, subject to approval of the department head or the student’s Academic Advisor). Students are required to pass BE591 Graduate Seminar twice.

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, biomedical engineering, 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). Students are required to pass BE591 Graduate Seminar twice.

For the Ph.D.
The Ph.D. 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]
- Dissertation Research [30 credits]
The student's Academic Advisory Committee may require additional course work to address specific deficiencies in the student's background. Students are required to pass BE591 Graduate Seminar four times.

No later than the start of the third year after formal admittance to the Ph.D. program, students are required to pass a Ph.D. 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 course work in life sciences, biomedical engineering and mathematics. Admission to candidacy is officially conferred upon students who have completed their course credit requirements, exclusive of dissertation research credit, and passed the Ph.D. qualifying examination.

Students in the Ph.D. 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 3- or 4-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 Ph.D. 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 Ph.D. 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 Ph.D. 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.
Biomedical Engineering

Faculty
Core BME Program Faculty

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

K. L. Billiar, Assistant Professor; Ph.D., University of Pennsylvania

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

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

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

G. D. Pins, Assistant Professor; Ph.D., Rutgers University

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

Associated BME Program Faculty

Anderson, F. A., Ph.D.; Department of Surgery, UMMS

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

Camesano, T. A., Ph.D.; Department of Chemical Engineering, WPI

Carrington, W. A., Ph.D.; Department of Physiology, UMMS

Clancy, E. A., Ph.D.; Department of Electrical and Computer Engineering, WPI

Davis, M. A., M.D.; Department of Radiology, UMMS

Duong, T. Q., Ph.D.; Department of Psychiatry, UMMS

Fogarty, K. E., M.S.; Department of Physiology, UMMS

Glick, S. J., Ph.D.; Department of Radiology, UMMS

Grigg, P., Ph.D.; Department of Physiology, UMMS

Hoffman, A. H., Ph.D.; Department of Mechanical Engineering, WPI

King, M. A., Ph.D.; Department of Radiology, UMMS

Lifshitz, L. M., Ph.D.; Department of Physiology, UMMS

Loof, F. J., III, Ph.D.; Department of Electrical and Computer Engineering, WPI

Mardirossian, G., M.D., Ph.D.; Department of Radiology, UMMS

Paydarfar, D., M.D.; Department of Neurology, UMMS

Pedersen, P. C., Ph.D.; Department of Electrical and Computer Engineering, WPI

Savilonis, B. J., Ph.D.; Department of Mechanical Engineering, WPI

Shivkumar, S. S., Ph.D.; Department of Mechanical Engineering, WPI

Singer, J. J., Ph.D.; Departments of Physiology and Biochemistry and Molecular Pharmacology, UMMS

Soller, B. R., Ph.D.; Department of Surgery, UMMS

Sullivan, J. M., Ph.D.; Department of Mechanical Engineering, WPI

Tang, D.; Department of Mathematical Sciences, WPI

Tuft, R. A., Ph.D.; Department of Physiology, UMMS

Walsh, J. V., M.D.; Department of Physiology, UMMS

Wang, Y-L., Ph.D.; Departments of Cell Biology and Physiology, UMMS

Wolf, D. E., Ph.D.; Department of Physiology, UMMS

Adjunct BME Faculty

Leal, M. J., M.S.; U.S. Food and Drug Administration

Rodger, R. M., D.V.M.; Veterinarian, Private Practice
Program of Study
The Worcester Consortium Ph.D. Program in Biomedical Sciences is an innovative program created and administered by WPI. The Consortium, for this program, 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 these Consortium institutions. Admission to the program requires evidence of substantial post-baccalaureate 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 and must meet the general degree requirements of WPI as well as requirements specified by the department through which they enter. A detailed description of procedures and degree requirements is available in the office of the biology and biotechnology department.

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 named consortium institutions or from another accredited institution subject to the following criteria:

- Must be graduate level courses with a final grade of B or better.
- Research credits are not transferable.
- 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, Clark University, 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 may also be 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 and 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. A student who fails the dissertation defense 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.
Programs of Study
Students have the opportunity to do cre-
ative work on state-of-the-art research pro-
jects as a part of their graduate study in
chemical engineering. The programs offers
excellent preparation for rewarding careers
in research, industry or education.
Selection of graduate courses and thesis
project is made with the aid of a faculty
advisor 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
ingineering is concerned with the
advanced topics of the field. While special-
ization 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 with course work alone,
most students carry on research terminat-
ing in a thesis.

In the doctoral program, a broad knowl-
edge of chemical engineering topics is
required for success in the qualifying
examination. Beyond this point, more
intensive specialization is achieved in the
student's field of research through course
work and thesis research.

Research Interests
The Chemical Engineering Department's
research effort is concentrated in the follow-
ing major areas: advanced materials process-
ing, biochemical engineering, biomedical
engineering, process control and environ-
mental engineering. Advanced materials
processing encompasses catalysis, reaction
engineering, and zeolite science and tech-
nology.

Biochemical engineering includes bioreac-
tor engineering and bioseparations while
biomedical engineering studies are focused
on cell-surface interactions. Environmental
Engineering encompasses air pollution and
atmospheric aerosols, and pollution pre-
vention in chemical processes, environ-
mentally benign chemical reactor technol-
ogy, fuel cell technology and new environ-
mentally benign catalytic processes. Process
control involves analysis and control of
nonlinear processes. Master's and doctoral
candidates' research in these areas involves
the application of all fundamental aspects
of chemical engineering.

Of the 30 to 35 graduate students, approxi-
matel 75% are Ph.D. candidates.
Research groups tend to be small; because
of this, the students find considerable interac-
tion with faculty advisors as well as among
various research groups. In such an atmos-
phere, graduate students have exceptional
opportunities to contribute to their field.
Studies may be pursued in the following
areas:

Advanced Materials Processing

Catalysis and Reaction Engineering
Research in this area is centered around
the physical and chemical behavior of flu-
ids, especially gases, in contact with homo-
genous and heterogeneous catalysts.
Projects include diffusion through porous
solids, multicomponent adsorption, mechan-
ism studies; microkinetics, synthesis and
characterization of catalysts; catalytic
reformers; heat and mass transfer in cata-
lytic reactors; and reactor dynamics.

Zeolite Science and Technology
Research in the area of zeolite science
involves synthesis, characterization and
applications of molecular sieve zeolites. In
particular, developing an understanding of
the fundamental mechanisms of zeolite
nucleation and crystal growth in
hydrothermal systems is of interest. Uses of
zeolite as liquid and gas phase adsorbents,
and as catalysts, are being studied.
Incorporation of zeolites into membranes
for separations is being investigated due to
zeolites' very regular pore dimensions on
the molecular level.

Solid-State Characterization
The primary focus in this area is the use of
optical spectroscopy in the structural char-
acterization of materials, especially cata-
yysts.

Biochemical Engineering

Bioreactor Engineering: Whole Cells
Research in this area centers around stud-
ies 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 reac-
tor environments. Recently, we have
explored the relationship between the
stress response and overproduction of
recombinant protein products.

Bioreactor Engineering:
Plant Tissue Culture
Plants are an important source of pharma-
aceutically active compounds. Many of
these secondary metabolites are only pro-
duced 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 micropropagation 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 opti-
mize production. This work is a collabora-
tive 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 trans-
port 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 elec-
trophoretic separation method.
Chemical Engineering

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

Process Analysis and Control Nonlinear Process
Current research efforts lie in the broad area of nonlinear process analysis and control, and are directed toward a fundamental understanding of certain key issues which are present in the analysis and synthesis of control systems for nonlinear processes in both continuous and discrete-time domain. In particular, the following thematic areas may be identified in our current research plan: (1) synthesis of robust optimal continuous and discrete-time (digital) feedback regulators for nonlinear processes in the presence of model uncertainty; (2) design of discrete-time nonlinear state estimators for digital process monitoring and fault detection/diagnosis purposes; (3) risk analysis and management with applications to process safety; (4) development of the appropriate software tools for the effective digital implementation of the above control, monitoring and risk management schemes; and (5) design and conduct of process dynamic analysis, control, monitoring and diagnostics-related experiments associated with a variety of operation units in the process control lab for educational, training and research purposes.

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.

Bacterial and Biopolymer Interactions in the Aquatic Environment
Interests are directed to the roles bacteria and bacterial extracellular polymers play in environmental processes. Experimental work is focused at characterizing biocolloid systems at the nanoscale. The main areas of environmental research are: (1) transport of bacteria in porous media, (2) adhesion of bacteria to soil or to the natural organic matter coatings present on soil, (3) the role of biopolymers in promoting bacterial adhesion, and (4) the role of biopolymers in coagulation of trace metals in surface water. The applications involve natural and engineered systems, and include improving in situ bioremediation efforts, prevention of water contamination with either microbes or toxic compounds, and the design of better treatment options for wastewater.

Environmental Catalysis and Reactor Design
The use of catalysis to solve problems of environmental importance is emphasized. New processes that will avoid the production of pollutants and also processes that will recycle undesired products are explored. Working closely with industry to identify significant issues is important. Design of novel reactors to minimize the formation of harmful unwanted side products is being carried out, with present emphasis on membrane reactors and preventing thermal runaway in fixed-bed reactors. Novel-supported molten metal catalysts are being developed for pollution abatement.

Fuel Cell Technology
Fuel cells have potential as clean and efficient power sources for automobiles and stationary appliances. Research is being conducted on developing, characterizing and modeling of fuel cells that are robust for these consumer applications. This includes development of CO-tolerant anodes, higher temperature proton-exchange membranes and direct methanol fuel cells. In addition, reformers are being investigated to produce hydrogen from liquid fuels.

Chemical Engineering Laboratories
Biocolloid Laboratory
All of the experimental work in this lab is geared at characterizing biocolloid systems (bacterial cells, biopolymers, other types of cells, etc.) at the nanoscale. The main piece of equipment used is an atomic force microscope, which can operate in liquids or under ambient conditions. Computers with sophisticated image analysis software are used to quantify phenomena observed in the images. A laminar flow hood is used for working with sterile cultures, and ample wet chemistry space to do preparative work.

Bioreactor Engineering Laboratory
This laboratory has stirred-tank, packed-bed and membrane-type bioreactors used in the production of biological products.

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 Celsoscope.

Heat and Mass Transfer Laboratory
This laboratory is mainly computational. Workstations are dedicated to the application of computational fluid dynamics
(CFD) to transport problems in chemical reaction engineering. Current research interests include simulation of flow and heat transfer in packed-bed reactors and membrane reactors. Capabilities also exist in this lab for simulation of gas dynamics in microchannels. Experimental facilities include the measurement of heat and mass transfer coefficients in packed columns.

**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, using 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.

**Environmental Catalysis Laboratory**
Kinetics on industrial catalysts and their flat model replicas are studied. For the industrial catalysts, kinetics is measured in flow, batch and CSTR reactors. The product analysis is made with gas chromatographs (GC), mass spectrometers (MS) or GC-MS. Other characterization methods are temperature-programmed reaction with an MS detector and volumetric cell apparatus for the determination of total and metal surface areas. Studies under reaction conditions are carried out with ultraviolet and visible Raman spectrometers.

**Catalyst and Reaction Engineering Laboratory (CREL)**
A large variety of equipment is available in CREL for catalyst preparation and characterization, and detailed kinetic studies. This includes various reactors such as several packed-bed reactors, a Parr reactor, a slurry reactor, a membrane reactor, a porous-walled tubular reactor and an adiabatic tubular reactor with several thermocouples for monitoring temperature. All necessary analytical instruments are also available, such as several microbalances, volumetric BET apparatus, mercury porosimeter, several gas chromatographs, a Perkin-Elmer GC-MS with Q-Mass 910 mass spectrometer, Nicolet Magna-IR 560 FTIR with DRIFT cell for catalyst surface characterization, Rosemount Chemiluminescence NO/NOx Analyzer NGA 2000 and a TEOM Series 1500 PMA Pulse Mass Analyzer for TPD/TGA experiments. Other available equipment in CREL includes hoods, several HPLC liquid feed pumps; several vacuum pumps; temperature, pressure and flow monitors and controllers, furnaces, vacuum oven, diffusion cell, and all necessary glassware and other laboratory supplies for catalyst preparation and testing. In addition, several Macintosh computers and PCs are available within the laboratory. The available equipment is used for the design, synthesis and characterization of novel catalytic materials, and for reactor analysis.

**Fuel Cell Laboratory (FCL)**
A 5 cm² and a 25 cm² proton-exchange membrane (PEM) fuel cell test station—complete with flow, pressure, humidity and temperature controllers, and an external electronic load (HP Model No. 6060B) with a power supply (Lambda LFS-46-5) —are available. In addition, a direct methanol fuel cell (DMFC) is available. A hot press, Carver Model C—along with other equipment for casting membranes and for fabricating membrane-electrode assemblies (MEAs) including catalyst preparation equipment—is available. A cell for studying conductivity at different relative humidities and temperatures is available. Other equipment includes a Solartron SI 1260 AC Impedance Analyzer and a rotating disc electrode. The available equipment allows design and thorough characterization of new fuel cells, including cyclic voltammetry and frequency analysis.
Chemical Engineering

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

Fuel Cell Center (FCC)
The Fuel Cell Center is a University/industry alliance comprising industrial members, faculty members, staff, and graduate and undergraduate students. The faculty members of FCC come from the various departments at WPI. The research is performed in the various laboratories of the faculty members. The industrial members represent companies or other organizations with interest in fuel cell technology, including fuel cell companies, automobile manufacturers, utilities, petroleum companies, chemical companies, catalysis companies, etc.

The objectives of the FCC are: (1) to perform research and development of fuel cells, fuel reformers and related components for mobile and stationary applications; (2) to educate graduate and undergraduate students in fuel cell technology; and (3) to facilitate technology transfer between the University and industry. The current projects include development of proton-exchange membrane (PEM) fuel cells, direct methanol fuel cells (DMFCs), molten carbonate fuel cells (MCFCs), microbial fuel cells, fuel cell stacks, membrane reformers, microreformers, reformer catalysis, fuel cell electrocatalysis, composite proton-exchange membranes, inorganic membranes, and transport and reaction modeling.

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 proposal 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 and doctoral degree applicants. Those with related backgrounds will also be considered, but may be required to complete prerequisite course work in some areas.

Faculty
R. Datta, Professor and Department Head; Ph.D., University of California, Santa Barbara
T. A. Camesano, Assistant Professor; Ph.D., Pennsylvania State University
W. M. Clark, Associate Professor; Ph.D., Rice University
D. DiBiasio, Associate Professor; Ph.D., Purdue University
A. G. Dixon, Professor; Ph.D., University of Edinburgh
N. K. Kazantzis, Assistant Professor; Ph.D., University of Michigan
Y. H. Ma, Professor; Ph.D. Massachusetts Institute of Technology
W. R. Moser, Professor Emeritus; 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
B. E. Wyslouzil, Professor; Ph.D., California Institute of Technology
Programs of Study
The Department of Chemistry and Biochemistry offers the M.S. in either chemistry or biochemistry, as well as a Ph.D. The major areas of research in the department are biochemistry and biophysics, molecular engineering and syntheses, and nanotechnology. As graduate education in chemistry and biochemistry is primarily research oriented, there are no formal course requirements other than participation in seminar in every semester of residence. It is expected that students will begin their research in collaboration with a faculty member by the end of the first term of residence.

Research Interests
The three major areas of research in the department are:

- Biochemistry and biophysics. Within this area there is active research on a number of topics including heavy metal transport and metal homeostasis of both plants and bacteria, plant pathogen interactions, enzyme structure and function, regulation of plant development by light, and others.

- Molecular Engineering and Synthesis. Within this area there is active research on topics encompassing supramolecular materials, photovoltaic materials, polymorphism in pharmaceutical drugs, spectroscopy of heterocyclic molecules, photophysical properties of cumulenes, host-guest chemistry, and more.

- Nanotechnology. This research area encompasses such projects as photonic and nonlinear optical materials, nanoporous and microporous crystals of organic and coordination compounds, molecular interactions at surfaces, and others.

Chemistry and Biochemistry Laboratories
The Chemistry and 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, 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, capillary electrophoresis, DSC (differential scanning calorimeter), TGA (thermogravimetric analysis), polarizing optical stenomicroscope, FT-IR, UV-VIS absorption, flourescence and phosphorescence spectroscopy; and cyclic voltammetry. The department is exceptionally well set up with computer facilities and is also networked to the University's mainframe.

Degree Requirements
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, or biochemistry), as revealed by preliminary examinations, will 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.

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, and the remainder in approved independent studies and courses at the 4000 or 500 level. Special requirements of the Chemistry and 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 and Biochemistry Department.

For the Ph.D.
Qualifying Examination
After formal admission to the doctoral program Ph.D. candidates must take the qualifying examination in their field of specialization.

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 and 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 or not the student should complete a master of science degree, or if the student should be formally admitted to the Ph.D. program.

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

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

Faculty
J. P. Dittami, Professor and Department Head; Ph.D., Rensselaer Polytechnic Institute
J. M. Argüello, Associate Professor; Ph.D., Universidad Nacional de Rió Cuarto, Argentina
H. Beall, Professor; Ph.D., Harvard University
L. H. Berka, Research Professor; Ph.D., University of Connecticut
R. E. Connors, Professor; Ph.D., Northeastern University
C. D. Fairchild, Assistant Professor; Ph.D., University of California, Berkeley
W. D. Hobey, Associate Professor; Ph.D., California Institute of Technology
N. K. Kildahl, Professor; Ph.D., University of Illinois
W. G. McGimpsey, Professor; Ph.D., Queen's University, Canada
J. MacDonald, Assistant Professor; Ph.D., University of Minnesota
J. W. Pavlik, Professor; Ph.D., George Washington University
A. A. Scala, Professor; Ph.D., Polytechnic Institute of Brooklyn
V. R. Thalladi, Assistant Professor; Ph.D., University of Hyderabad, India
S. J. Weininger, Professor; Ph.D., University of Pennsylvania
K. K. Wobbe, Associate Professor; Ph.D., Harvard University
Civil and Environmental Engineering

Programs of Study
http://www.wpi.edu/Academics/Depts/CEE/Grad

The Department of Civil and Environmental Engineering (CEE) offers graduate programs leading to the degrees of master of science, master of engineering and doctor of philosophy. The department also offers graduate and advanced certificate programs. Full- and part-time study is available.

Master of Science and Doctor of Philosophy

The master of science and doctor of philosophy in civil and environmental engineering are arranged to meet the interests and objectives of the individual student. Through consultation with an advisor and appropriate selection from the courses listed in this catalog, from 4000-level undergraduate courses suitable for graduate credit, independent graduate study and 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 Coordinator.

The faculty have a broad range of teaching and research interests. Through courses, projects and research, students gain excellent preparation for rewarding careers in many sectors of engineering, including consulting, industry, government and education.

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

Environmental Engineering

The environmental engineering program is designed to meet the needs of engineers and scientists in the environmental field. Coursework provides a strong foundation in both the theoretical and practical aspects of the environmental engineering discipline, while project and research activities allow for in-depth investigation of current and emerging topics. Courses are offered in the broad areas of water quality and waste treatment. Topics covered in classes include: hydraulics and hydrology; physical, chemical and biological treatment systems for water, wastewater, hazardous waste and industrial waste; contaminant transport, transformation and modeling; and water quality.

Current research interests in the environmental engineering program span a wide range of areas. These areas include microbial contamination of source waters, colloid and surface chemistry, physicochemical treatment processes, disinfection, pollution prevention for industries, treatment of hazardous and industrial wastes, biological wastewater treatment, environmental fluid dynamics and coastal processes, contaminant fate and transport in groundwater and surface water, exchanges between surface and subsurface waters, computer simulations of distribution systems, and land use development and controls. Research facilities include the Environmental Laboratory and several computing laboratories. Additional 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 soil mechanics, geotechnical and geoenvironmental engineering may be combined with structural engineering and engineering mechanics courses, as well as other appropriate University 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 four required courses: CE 580, CE584, CE585 and MG 501. MG 501 can be substituted by an equivalent 3-credit-hour course approved by department. It must also include any two of the following courses: CE 581, CE 582, CE 583 and CE 586. The remaining courses in the students' program include 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 crash-worthiness, 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**

The interdisciplinary program 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 in 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.E. program is offered in the following two 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.

**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 located within Kaven Hall, as well as a structural mechanics impact laboratory. The CEE 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 laboratories include formal classes, student projects, research projects and unsupervised student activities.

**Structural Mechanics Impact Laboratory**

The Structural Mechanics Impact Laboratory is a teaching and research laboratory. The impact laboratory is used to explore the behavior of materials and components in collisions.

The Structural Mechanics Impact Laboratory consists of the following major pieces of equipment:

- An Instron Dynatup Model 8250 Instrumented Impact Test System,
- A high-speed video camera system,
- A data acquisition system, and
- A large-mass drop tower.

**Fuller Environmental Laboratory**

The Fuller Laboratory is designed for state-of-the-art environmental analyses, including water and wastewater testing.
and treatability studies. Major equipment includes an atomic absorption spectrophotometer, gas chromatograph, total organic carbon analyzer, UV-Vis spectrophotometer and particle counter. Along with ancillary equipment (such as a centrifuge, autoclave, incubators, balances, pH meters and water purification system), the laboratory is equipped for a broad range of physical, chemical and biological testing. The laboratory is shared by graduate research projects, graduate and undergraduate courses (CE 4060 Environmental Engineering Laboratory and CE 569 Environmental Engineering Treatability Laboratory) and undergraduate projects.

**Materials/Structural Laboratory**
The Materials/Structural Laboratory is set up for materials and structures testing. The laboratory is utilized for undergraduate teaching and projects, and graduate research. The laboratory is equipped for research activities including construction materials processing and testing. Materials tested in this lab include Portland cement, concrete, asphalt, and fiber composites. The laboratory has several large-load mechanical testing machines.

**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**
Computer Laboratory No. 1 (2000 square feet, referred to as the Stat Lab because of its association with the Mathematics Department) contains 28 X-terminals connected to WPI’s UNIX network system. This facility has a complete presentation system (with PC, computer projector, VCR and sound system). Primary use of this laboratory is for courses and civil engineering group project work. The Computer Laboratory No. 1 contains 24 Pentium 400 computers connected to WPI’s network system. In addition, laptop computers are provided at four large group tables in the center of the CECIL room. A complete presentation system (computer projector, VCR and sound system) is in this facility. Primary use of this laboratory is for courses and civil engineering group project work.

**Graduate Research Computing Laboratory (GRCL)**
The GRCL is located in Kaven Hall, Room 203. The laboratory is for the use of civil and environmental engineering graduate students in the pursuit of their research and course work. The GCRL contains the following equipment:
- 4 dual-processor Pentium computers (WindowsNT),
- 4 single-processor Pentium computers (Windows98),
- 1 Pentium computer with a digitizer pad,
- 1 Power PC with a scanner, and
- 1 HP LaserJet printer.

All the hardware is connected to the WPI network. The Civil and Environmental Engineering Department is continually adding hardware and software to this facility in support of research activities in the department.

**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.E.**
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 Project), competence in integration of computer applications and information technology (CE 585 Information 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 course work in at least two subfields of civil and environmental engineering that are related to the M.E. 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, waste management, and impact engineering. 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 complement the program. Course work 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.E. Program**
A student may transfer from the M.E. program to the M.S. program at any time. A student may transfer from the M.S. program to the M.E. program only after an integrated program of study has been agreed upon by the student and the advi-
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, the CEE department requires students to establish a minor and to pass a 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’s dissertation committee should represent the minor area. The student’s dissertation committee has the authority to make decisions on academic matters associated with the Ph.D. program. To become a candidate for the doctorate, the student must pass a comprehensive examination administered by the student’s dissertation committee. The candidate, on completion and submission of the dissertation, must defend it to the satisfaction of the dissertation 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. 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 degrees in areas such as architecture, management engineering and civil engineering technology 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.E.
A B.S. degree in civil engineering (or another acceptable engineering field) is required for admission to the M.E. 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 is administered to each student by the department Graduate Program Committee. The candidate, on completion and submission of the dissertation, must defend it to the satisfaction of the dissertation committee.

Faculty

F. L. Hart, Professor and Department Head; Ph.D., University of Connecticut
L. D. Albano, Associate Professor; Ph.D., Massachusetts Institute of Technology
R. K. Allen, Adjunct Associate Professor; J.D., Franklin Pierce Law Center
J. Bergendahl, Assistant Professor; Ph.D., University of Connecticut
D. N. Brocard, Adjunct Associate Professor; Ph.D., Massachusetts Institute of Technology
J. F. Carney III, Provost and Vice President for Academic Affairs, Professor; Ph.D., Northwestern University
R. A. D’Andrea, Associate Professor; Ph.D., Cornell University
T. El-Korchi, Professor; Ph.D., University of New Hampshire
A. G. Ferron, Adjunct Associate Professor; B.S., WPI
R. W. Fitzgerald, Professor; Ph.D., University of Connecticut
M. S. FitzPatrick, Associate Professor of Urban and Environmental Planning; Ph.D., Harvard University
P. Jayachandran, Associate Professor; Ph.D., University of Wisconsin
R. B. Mallick, Assistant Professor; Ph.D., Auburn University
P. P. Mathisen, Associate Professor; Ph.D., Massachusetts Institute of Technology
F. Mulligan, Adjunct Professor; M.S., WPI
J. C. O’Shaughnessy, Professor; Ph.D., Pennsylvania State University
M. Padmanabhan, Adjunct Associate Professor; Ph.D., Georgia Institute of Technology
R. Pietroforte, Associate Professor; Ph.D., Massachusetts Institute of Technology
J. D. Plummer, Assistant Professor; Ph.D., University of Massachusetts, Amherst
M. H. Ray, Associate Professor and White Chair; Ph.D., Vanderbilt University
G. F. Salazar, Associate Professor; Ph.D., Massachusetts Institute of Technology
J. K. Wakely, Adjunct Associate Professor; BS., University of Maine
Program of Study
A specialization in computer and communications networks is available within the master’s degree programs of the Computer Science (CS) and the Electrical and Computer Engineering (ECE) 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 (CCN).” 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.

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.

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

Elective Courses
(at least three from list):
• Digital Communications: Modulation and Coding (EE 532)
• Advances in Digital Communication (EE 533)
• Multiple Processor and Distributed Systems (EE 575/CS 551)
• Advanced Operating System Theory (CS 535)
• Design of Software Systems (CS 509)
• Wireless Information Networks (EE 538)
• Cryptography and Data Security (CS 578/EE 578)
• Advanced Cryptography (EE 579R)
• Telecommunication Policy (EE 508)
• Mobile Data Networking (EE 539S)
• Any of the courses EE 535, EE 530/CS 535, EE 537/EE 577, and CS 535/EE 581 not taken to satisfy the required courses above.

Degree Requirements

Computer Science
33 credits

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

Required Courses
(4 courses, 12 credits):
• Analysis of Probabilistic Signals and Systems or Analysis of Computations and Systems (EE 502 or CS 504)
• Introduction to Local- and Wide-Area Networks (CS 513/EE 506) and two of the following courses:
  • Telecommunications Transmission Technologies (EE 535)
  • High Performance Networks (CS 530/EE 530)
  • Advanced Computer and Communications Networks (EE 537/CS 577)
  • Modeling and Performance Evaluation of Networks and Computer Systems (CS 533/EE 581)

Elective Courses
(at least three from list):
• Analysis of Probabilistic Signals and Systems or Analysis of Computations and Systems (EE 502 or CS 504)
• Introduction to Local- and Wide-Area Networks (CS 513/EE 506) and two of the following courses:
  • Telecommunications Transmission Technologies (EE 535)
  • High Performance Networks (CS 530/EE 530)
  • Advanced Computer and Communications Networks (EE 537/CS 577)
  • Modeling and Performance Evaluation of Networks and Computer Systems (CS 533/EE 581)

Elective Courses
(at least three from list):
• Digital Communications: Modulation and Coding (EE 532)
• Advances in Digital Communication (EE 533)
• Multiple Processor and Distributed Systems (EE 575/CS 551)
• Advanced Operating System Theory (CS 535)
• Design of Software Systems (CS 509)
• Wireless Information Networks (EE 538)
• Cryptography and Data Security (CS 578/EE 578)
• Advanced Cryptography (EE 579R)
• Telecommunication Policy (EE 508)
• Mobile Data Networking (EE 539S)
• Any of the courses EE 535, EE 530/CS 535, EE 537/EE 577, and CS 535/EE 581 not taken to satisfy the required courses above.
Computer and Communications Networks

CCN Project
The student must complete one of the following:

1. Computer and Communications Networks 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 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 electrical engineering (EE) and/or computer science (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.

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

Research Interests
The current departmental activities include, among other areas, analysis of algorithms, artificial intelligence, computer vision, computer graphics, database and information systems, distributed systems, graph theory and computational complexity, network performance evaluation, programming languages, 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 the 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 and fire protection engineering. Students are also encouraged to undertake projects and theses in cooperation with neighboring computer manufacturers or commercial organizations.

Computer Science Laboratories
The Computer Science (CS) 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 an artificial intelligence lab, a performance evaluation and distributed systems lab, a database systems lab, a software engineering lab, an advanced information systems lab and a 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 SPARC-Solaris, SGI and Sun machines, as well as numerous PCs, terminals and workstations. The College Computing Center (CCC) provides additional resources, such as a supercomputer and large displays.

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

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 these alternatives in consultation with his or her advisor prior to selecting an option, typically in the second year of study. The department will allow a student to change options only once.

Thesis Option
At least 33 credit hours, including the thesis, must be satisfactorily completed. A thesis consisting of a research or development project worth a minimum of 9 credit hours must be completed and presented to the faculty. A thesis proposal must be approved by the department by the end of the semester in which a student has registered for a third thesis credit. Proposals will be considered only at regularly scheduled department meetings. The 33 credit hours must include at least one course from each of the core areas. Students should endeavor to take these required four courses as early as possible so as to provide the background for the remaining graduate work. The remaining courses may, with prior approval of the student’s advisor, consist of computer science courses, independent study, or courses elected from other disciplines. (CS 501 and CS 507 cannot be counted toward the required course credits.) At most, two courses in other disciplines will be accepted.
Course Work Option
A total of at least 33 credit hours must be satisfactorily completed, including at least one course from each of the core areas. Students should endeavor to take these required courses as early as possible so as to provide the background for the remaining graduate work. The remaining seven courses may, with prior approval of the student’s advisor, consist of computer science courses, independent study, or up to two courses elected from other disciplines. (CS 501 and CS 507 cannot be counted toward the required course credits.)

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

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 credits of transfer credit from other graduate programs. If appropriate, this transferred credit may be used to satisfy core area requirements. These credits must not have been used to satisfy the requirements of another academic degree earned by the candidate. With rare exceptions, these credits are limited to courses taken before matriculation at WPI.

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. 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.

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.

Faculty
M. Hofri, Professor and Department Head; D.Sc., Technion-ITT, Haifa, Israel
E. O. Agu, Assistant Professor; Ph.D., University of Massachusetts, Amherst
L. A. Becker, Associate Professor; Ph.D., University of Illinois
D. C. Brown, Professor; Ph.D., Ohio State University
M. L. Claypool, Assistant Professor; Ph.D., University of Minnesota
D. J. Dougherty, Professor; Ph.D., University of Maryland
D. Finkel, Professor; Ph.D., University of Chicago
K. Fisler, Assistant Professor; Ph.D., Indiana University
M. A. Gennert, Associate Professor; Sc.D., Massachusetts Institute of Technology
G. T. Heineman, Associate Professor; Ph.D., Columbia University
N. T. Heffernan, Assistant Professor; Ph.D., Carnegie-Mellon University
R. E. Kinicki, Associate Professor; Ph.D., Duke University
K. A. Lemone, Associate Professor; Ph.D., Northeastern University
F. C. Colon Osorio, Research Associate Professor; Ph.D., University of Massachusetts, Amherst
C. Ruiz, Assistant Professor; Ph.D., University of Maryland
E. A. Rundensteiner, Associate Professor; Ph.D., University of California at Irvine
G. N. Sarkozy, Affiliate Associate Professor; Ph.D., Rutgers University
S. M. Selkow, Professor; Ph.D., University of Pennsylvania
M. O. Ward, Professor; Ph.D., University of Connecticut
C. E. Wills, Associate Professor; Ph.D., Purdue University
Electrical and Computer Engineering

Programs of Study
The Electrical and Computer Engineering (ECE) Department offers programs leading to the M.S. and Ph.D. degrees in electrical engineering, as well as graduate and advanced certificates. 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, and systems and controls.

Research Interests
Listed are the major areas of specialization in which Electrical and Computer Engineering (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, non-destructive 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 Analog Microelectronics Laboratory was opened in 1998, funded by an NSF grant for the purchase of test and measurement equipment, which is dedicated to support work in the areas of high-speed data communication, high-speed imaging, and mixed signal circuit characterization. In addition to the direct impact on research, this equipment will also enable the Analog Microelectronics Laboratory to become a valuable resource for educating both undergraduates and graduate students in the complete integrated circuit design process. The lab focuses on three specific areas:
1. Analog microelectronics for telecommunication has a goal to guide IC design by connecting system-level performance to fundamental limits imposed by circuit-level considerations, for example thermal and shot noise.
2. High-speed imaging research applies analog techniques to improve performance in high-speed, wide dynamic range electronic imaging systems. Applications include machine vision and adaptive optics.
3. Mixed signal circuit characterization is concerned with developing techniques for measuring and modeling second order error sources in mixed signal circuits, for example, code-dependent noise in analog-to-digital converters.

Center for Wireless Information Networking Studies (CWINS)
This center is recognized as a pioneering facility in the important and rapidly growing area of wireless personal and data communications. The lab is supported by a broad range of networking and telecommunications corporations.

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

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

Computer Architecture Laboratory
This laboratory contains facilities for the research and development of single-processor and multiprocessor 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 and 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 on 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.

Center for Sensory and Physiologic Signal Processing — C(SP)²
Researchers within the C(SP)² apply signal processing, mathematical modeling, and other electrical and computer engineering skills to study issues related to human sensation and physiology. Currently, our major focus areas are vision, hearing, tactile reception and electromyography (EMG). In our vision research, we have digitally produced pulse-code-modulated patterns that evoke multicolor sensations from black-and-white and monochromatic flicker patterns. Hearing research is concentrating on improved signal processing in hearing aid devices, to improve speech perception by the hearing impaired. The purpose of the tactile receptor studies is to develop an understanding of the stimulus encoder characteristics of tactile mechanoreceptors. In the area of EMG (the electrical activity of skeletal muscle), efforts are being made to improve the detection and interpretation of EMG for such uses as the control of powered prosthetic limbs and musculoskeletal modeling.

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 (GPS). Receivers, signal processors and computers are provided for work on utilization of the DOD GPS system for civilian purposes, especially aircraft navigation and landing.

Ultrasounds Laboratory
Facilities in this laboratory are set up for performing basic ultrasound studies in the areas of basic acoustic research, transducer development, non-destructive 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 FPGAs and Altera EPLDs to new types of cryptosystems, 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 is the high-speed Asynchronous Transfer Mode network. 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 United States 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.

Signal Processing and Information Networking Laboratory (SPINLab)
SPINLab was established in 2002 with the primary mission of analyzing and developing new linear and nonlinear signal processing techniques to improve the performance of high-speed information networks. Currently, our major focus areas include channel identification and equalization, synchronization, interference cancellation, and multuser detection for copper, optical and wireless channels. We have also recently begun to study software radio techniques for efficient implementa-
tion of digital communication systems and signal processing algorithms. SPINLab has established relationships with several telecommunications corporations and offers research opportunities at both the graduate and undergraduate levels. For more details, please see the SPINLab Web page at http://spinlab.wpi.edu.

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 the 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.
The degree of doctor of philosophy is conferred on candidates in recognition of high scientific attainments and the ability to carry on original research. The doctoral student must establish two minors in fields outside of electrical engineering. Physics, mathematics and computer science are usually recommended. Each student selects the minors in consultation with the Major Advisor. At least 6 credits of graduate work is required in each minor area. Courses with an ECE designation which are cross-listed in the course offerings of another department cannot be used toward 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, 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 of 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 department. Failure to pass the exam more than twice will result in the student being removed from the graduate program.

**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 the Major Advisor.

**For the Combined B.S./Master's Program**

A student accepted into the B.S./Master'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./Master'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.

A student who intends to complete the B.S./Master's program is required to be a full-time graduate student until the M.S. degree requirements are met. Any student who is accepted into the B.S./Master's program and who elects to finish the M.S. degree part time will be required to meet the normal, non-B.S./Master's program degree requirements.

**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 to the M.S. or Ph.D. program. Students with the bachelor of technology or the bachelor of engineering technology degree must complete about 1-1/2 years of undergraduate study in electrical engineering before they can be admitted to the graduate program.

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

**Basic skills**

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

**Specialized skills**

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

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

Faculty

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

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

E. A. Clancy, Assistant Professor; Ph.D., Massachusetts Institute of Technology

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

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

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

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

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

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

Brian King, Assistant Professor; Ph.D., University of Arizona

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

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

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

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

D. Papageorgiou, Assistant Professor; Ph.D., University of Michigan

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

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

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

J. M. Sullivan, Jr., Associate Professor; D.E., Dartmouth College

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

R. F. Vaz, Associate Professor; Ph.D., WPI
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 or 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 23). 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.

Combined B.S./Master’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 bachelor of science 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 with on-campus classroom and laboratory activities. With departmental permission, students may take courses during the full-time work cycle.

Center for Firesafety Studies

The Center for Firesafety Studies serves as a crossroads for bringing together talents from many disciplines to focus on fire and explosion safety problems. Operating as a self-standing academic department, the center features formal degree and certificate programs in fire protection engineering, continuing education for the practitioner, and research to uncover new knowledge about fire behavior and fire protection methods.

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 detection and suppression, fire and smoke dynamics, wildfire phenomena, firesafety design methods for buildings and marine applications, explosion phenomena, failure analysis, risk assessment, material composites and regulatory reform.

Fire Science Laboratory

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

The 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.

**Fire Modeling Laboratory**
The Fire Modeling Laboratory specializes in computer applications to fire protection engineering and research. Research activities include computational fluid dynamics modeling of building and vehicle fires, and flame spread model development.

**Degree Requirements**

**For the M.S.**
The program for a master of science in fire protection engineering is flexible and can be tailored to individual student career goals. The fire protection engineering master’s degree requires 30 semester hours of credit. Both a thesis and non-thesis option are offered.

**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, a research proposal and public seminar, and the dissertation defense.

**Admission Requirements**
High school graduates applying for the Combined B.S./Master’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.

**Faculty**

- **D. A. Lucht**, Professor of Fire Protection Engineering and Director; B.S., Illinois Institute of Technology
- **J. R. Barnett**, Professor of Fire Protection Engineering; Ph.D., WPI
- **E. V. Clougherty**, Adjunct Professor; Ph.D. Chemistry, Boston University
- **R. L. P. Custer**, Adjunct Professor
- **D. A. Dembsey**, Visiting Scholar; M.S. Physics, University of Michigan
- **N. A. Dembsey**, Associate Professor of Fire Protection Engineering; Ph.D., University of California at Berkeley
- **R. W. Fitzgerald**, Professor of Fire Protection Engineering and Civil Environmental Engineering; Ph.D., University of Connecticut
- **J. A. Ierardi**, Instructor; Ph.D. FPE, WPI (in progress)
- **H. Y. Kim**, Affiliate Professor
- **W. K. Kim**, Affiliate Professor; M.S. FPE, WPI
- **F. Noonan**, Associate Professor of Fire Protection Engineering and Management; Ph.D., University of Massachusetts
- **R. D. Pehrson**, Adjunct Assistant Professor; Ph.D. FPE, WPI
- **Patrick J. Pagni**, Affiliate Professor
- **Milosh T. Puchovsky**, Adjunct Assistant Professor
- **B. J. Savilonis**, Professor of Mechanical Engineering; Ph.D., State University of New York
- **J. P. Woycheese**, Assistant Professor of Fire Protection Engineering; Ph.D., University of California at Berkeley
- **E. S. Yoon**, Affiliate Professor; Ph.D. Chemical Engineering, MIT
- **R. G. Zalosh**, Professor of Fire Protection Engineering; Ph.D., Northeastern University
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.

A WPI 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 a 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, services 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 15-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 in Technological Organizations
- Creating Processes in Technological Organizations
- Business Analysis for Technological Managers
- 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 prerequisite 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
- Operations Management
- Quantitative Methods

For understanding disciplinary material that is critical for managers in a globally-competitive, technological world. Core courses include:

- Principles of Marketing
- Management Information Systems
- Economics of the Firm
- Domestic and Global Economic Environment of Business

Foundation-level courses are potentially waivable based on prior graduate or undergraduate course work.

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 course work, which may be taken within the Department of Management 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.

M.S. in Marketing and Technological Innovation

A highly specialized 32-credit-hour degree program 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 14 credit hours of required course work 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 in Technological Organizations.

Students then select 18 credit hours of electives from the following courses:

- MG 531 Managing Organizational Change
- MG 546 Managing Technological Innovation
- MG 548 Productivity Management
- MG 563 Marketing of Emerging Technologies
- MG 564 Global Technology Marketing
- MG 566 Marketing and Electronic Commerce
- MG 567 Integrated Marketing Communications
- MG 572 Telecommunications Management and Electronic Commerce
- MG 576 Project...
Management

Management, MG 592 New Venture Management and Entrepreneurship, MG 597 Internship, and MG 598 Independent Study.

Students who have completed prior undergraduate or graduate level course work 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 course work for each foundation course waived, either in the area of the waiver or in the “major” area.

M.S. in Operations and Information Technology

A highly specialized 30-credit-hour degree program specifically designed for individuals employed in or aspiring to work in production/operations positions, or management information systems (MIS) positions. The master’s in operations and information technology features 12 credit hours of required course work including:

- MG 503 Organizational Behavior
- MG 504 Operations Management
- MG 507 Management Information Systems
- MG 511 Interpersonal and Leadership Skills for Technological Managers
- MG 513 Creating Processes in Technological Organizations

Students then select 18 credit hours of electives from the following courses:

- MG 505 Quantitative Methods
- MG 531 Managing Organizational Change
- MG 541 Operations Risk Management
- 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 548 Productivity Management
- MG 549 Strategies for Manufacturing and Service Firms
- MG 566 Marketing and Electronic Commerce
- MG 568 Business Data Mining
- 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 576 Project Management
- MG 592 New Venture Management and Entrepreneurship
- MG 597 Internship
- MG 598 Global Operations Strategy
- MG 598 Independent Study

To obtain an M.B.A. via the Combined Program, the student must satisfy all M.B.A. degree requirements. In addition to the pre-requisite undergraduate courses listed above, the student must complete the following graduate courses:

- MG 511 Interpersonal and Leadership Skills for Technological Managers
- MG 512 Creating and Implementing Strategy in Technological Organizations
- MG 513 Creating Processes in Technological Organizations
- MG 514 Business Analysis for Technological Managers
- MG 515 Legal and Ethical Context of Technological Managers
- MG 516 Graduate Qualifying Project (GQP), and 12 elective credits.

Please refer to the section on the Combined Programs (page 21) 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

The Collaborative for Entrepreneurship and Innovation (CEI) is a program of the Department of Management, designed to inspire and nurture people to discover, create, and commercialize new technology-based products, services and organizations. It coordinates all entrepreneurship-related activity at WPI, including graduate and undergraduate courses; the CEI@WPI ALL-OUT $50K Business Plan Challenge; the WPI Venture Forum workshops, monthly lecture and case presentation programs, radio show and newsletter; networking; a student-run entrepreneurs organization; the New England Collegiate Entrepreneurs Award; Web site administra-
tion of the Coalition for Venture Support; and, on a periodic basis, the CEI will offer conferences, workshops and seminars on topics of interest to entrepreneurs. Programs for high school outreach, social entrepreneurship, internship opportunities, business incubation, various awards, an Entrepreneurship Fair and a Consortium-wide business plan contest are in the planning stage. Please call 508-831-5075 or 5218 for more information.

Degree Requirements
For the M.B.A.
49 credits, prior to waivers, distributed as follows (credit in parentheses):

- **9 Foundation Courses**
  (or graduate/undergraduate equivalents)
  MG 501, MG 502, MG 503, MG 504, MG 505, MG 506, MG 507, MG 508, MG 509 (2 credits each)

- **5 Core Courses**
  MG 511 (3 credits), MG 512 (3 credits), MG 513 (3 credits), MG 514 (4 credits), MG 515 (2 credits)

- **Graduate Qualifying Project (GQP)**
  MG 516 (4 credits)

- **4 Elective Courses**
  12 credits

For the M.S. in Marketing and Technological Innovation
32 credits, distributed as follows (credit in parentheses):

- **4 Foundation Courses**
  (or graduate/undergraduate equivalents)
  MG 503, MG 505, MG 506, MG 508 (2 credits each)

- **2 Core Courses**
  MG 511, MG 512 (3 credits each)

- **6 Elective Courses**
  selected from the following
  MG 531, MG 546, MG 548, MG 567, MG 563, MG 564, MG 566, MG 572, MG 576, 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 541, MG 542, MG 544, MG 545, MG 546, MG 548, MG 549, MG 566, MG 571, MG 572, MG 573, MG 575, MG 576, MG 592, MG 597, MG 568 (3 credits each)

All students admitted to a graduate management degree program are assigned a faculty advisor and must file a curriculum plan during their first year in the program. Part-time students typically complete the M.B.A. program in three to five years, dependent on prior academic background, while full-time students typically complete the program in two years. An M.S. degree program is typically completed in two to four years part-time, or one and a half years full-time.

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

Applicants should have the analytic aptitude and academic preparation necessary to complete a technology-oriented management program. This includes a minimum of three semesters of college level math or two semesters of college level calculus. Applicants are also required to have an understanding of computer systems.

Applicants must have the earned equivalent of a four-year U.S. bachelor's degree to be considered for admission. Admission decisions are based upon all the information required from the applicant.

Locations
Tailored to meet the challenges of working professionals, WPI offers full- and part-time graduate management study at our campuses in Worcester and Waltham, Massachusetts, as well as world-wide via our Advanced Distance Learning Network (see page 23).

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

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

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

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

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

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

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

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

S. McCoy, Assistant Professor; Ph.D., University of Pittsburgh

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

K. Mukherjee, Associate Professor; Ph.D., University of Connecticut

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

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

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

S. Taylor, Assistant Professor; Ph.D., Boston College

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

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

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

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

J. Zhu, Associate Professor; Ph.D., University of Massachusetts
Programs of Study
http://www.wpi.edu/+mfe/

The Manufacturing Engineering (MFE) Program offers two graduate degrees: the master of science and the doctor of philosophy. Full- and part-time study available.

The graduate programs in manufacturing engineering provide opportunities for students to study current manufacturing techniques while allowing each student the flexibility to customize their educational program. Course material and research activities often draw from the 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's intention is to build a solid and broad foundation in manufacturing theories and practices, and allow for further concentrated study in a selected specialty.

For the M.S.
The master of science (M.S.) program in Manufacturing Engineering (MFE) at WPI is highly flexible. Students from a wide range of engineering and management backgrounds can design individualized programs of study to meet their special needs and interests.

All candidates for the M.S. degree in MFE take four core courses (12 credits), providing a common foundation in design and control of manufacturing processes and systems, and design for manufacturability. The remaining 18 credits can be earned through almost any combination of courses, thesis, independent study, or directed research. Students, with their advisor, can select grad courses from virtually any department and can complete their degree entirely with course work. Thesis and directed research are available for those who would like to perform significant projects, working closely with a professor of their choosing, possibly involving sponsored research in one of WPI’s many research and teaching laboratories, and possibly off campus.

The four MFE core courses are offered in the evenings. The typical MFE core class is made up of about half practicing engineers with day jobs and half full-time grad students with teaching or research assistantships or fellowships.

For the Ph.D.
The doctoral (Ph.D.) program in MFE is a research degree, with no required courses. All candidates must pass a comprehensive exam, which is based on the material in the four core courses required for the M.S. degree in MFE. All candidates must complete at least one year in residence, have a dissertation proposal accepted, then complete the dissertation and defend it successfully.

The dissertation is based on original and, generally, externally sponsored research. A broad range of research topics is possible, including investigation into the fundamental science on which manufacturing processes are based, material science, manufacturing engineering education, metrology, quality, machine tool dynamics, manufacturing processes, design methodology and production systems.

MFE Seminar
Seminar speakers include WPI faculty and students as well as manufacturing experts and scholars from around the world. Registration for, attendance at and participation in the seminar course, MFE 500, is required for full-time students. The seminar series provides a common forum for all students to discuss current issues in manufacturing engineering.

Research Interests
Current research areas include tolerance analysis, CAD/CAM, production systems analysis, machining, fixturing, delayed dynamical systems, nonlinear chatter, surface metrology, fractal analysis, surface functionality, metals processing and manufacturing management.

Research Facilities and Laboratories
Graduate students in MFE can do their project, thesis and dissertation work in almost any research or production facility on or off campus. Often the work is done in one of the following facilities:

- Computer-aided Manufacturing Lab
- HAAS Center for Computer-controlled Machining
- Metals Processing Institute
- Production and Machine Dynamics Lab
- Robotics Lab
- Surface Metrology Lab

For more information, visit the MFE Web site: http://www.wpi.edu/+mfe/

Admission Requirements
Candidates for admission must meet WPI’s requirements and should have a bachelor’s degree in science or engineering, preferably in such fields as computer science/engineering, electrical/ control engineering, industrial engineering, environmental engineering, manufacturing engineering, materials science and engineering, or mechanical engineering. Students with other backgrounds will be considered based on their interest, formal education and experience in manufacturing.
Faculty

C. A. Brown, Director of Manufacturing Engineering, Saint Gobain Professor of Mechanical Engineering; Ph.D., University of Vermont

D. Apelian, Howmet Professor of Engineering, 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

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

D. C. Brown, Professor of Computer Science; Ph.D., Ohio State University

P. D. Cotnoir, Visiting Lecturer in Mechanical Engineering; M.S., WPI

M. A. Demetriou, Associate Professor of Mechanical Engineering; Ph.D., University of Southern California

M. S. Fofana, Associate Professor of Mechanical Engineering; Ph.D., University of Waterloo

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

R. N. Katz, Research Professor; Ph.D., Massachusetts Institute of Technology

R. Ludwig, Professor of Electrical and Computer Engineering; Ph.D., Colorado State University

M. M. Makhlouf, Professor of Mechanical Engineering, Director of Aluminum Casting Research Laboratory; Ph.D., WPI

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

J. C. O'Shaughnessy, Professor of Civil and Environmental Engineering; Ph.D., Penn State University

Y. Rong, Professor of Mechanical Engineering; Ph.D., University of Kentucky

R. D. Sisson Jr., Professor of Mechanical Engineering, Ph.D., Purdue University

J. M. Sullivan Jr., Associate Professor of Mechanical Engineering; Ph.D., Thayer School of Engineering, Dartmouth College
Program of Study
http://www.me.wpi.edu/MTE
Programs leading to a degree of master of science and/or doctor of philosophy.

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. Both full- and part-time study are available. For more information, contact the program head at 508-831-5633.

Program areas for the doctor of philosophy emphasize the processing-structure-property-performance relationships in metals, ceramics, polymers and composites. Current projects are addressing these issues in fuel cell materials, biopolymers, aluminum and magnesium casting, the heat treating of steels and aluminum alloys and metal matrix composites.

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, semisolid processing laboratories, a tribology laboratory, a metallographic laboratory, a polymer engineering laboratory with differential scanning calorimeter (DSC) and thermogravimetric 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.

Materials Science and Engineering Laboratories
Biomaterials Laboratory
http://www.me.wpi.edu/MTE/biomaterials.html
This laboratory contains facilities for the synthesis, processing and testing of biomaterials. The equipment includes 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
http://www.me.wpi.edu/MTE/ceramic.html
This industry-sponsored laboratory supports particular 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.

Mechanical Testing Laboratory
http://www.me.wpi.edu/MTE/mechtesting.html
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 of ceramic materials; an ASCERA hydraulic tensile tester for brittle materials; two high-temperature and three room-temperature stress-rupture systems.

Optical and Electron Metallography Laboratories
http://www.me.wpi.edu/MTE/optical.html
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 JSMD840 (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 micro-structural analysis and determination of crystal structures of fine phases present in metals and ceramics.

Polymer Engineering Laboratory
http://www.me.wpi.edu/MTE/polymer.html
This laboratory is used for the synthesis, processing and testing of plastics. The equipment includes: 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.

Surface Metrology Laboratory
http://www.me.wpi.edu/MFE/SurfMet/
http://www.wpi.edu/Academics/Depts/ME/MFE/SurfMet/
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
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 has also been utilized in specialized image analyses, used, for example, to characterize the internal morphology of ceramic membrane.

X-Ray Diffraction Laboratory
http://www.wpi.edu/MTE/xray.html
Two fully automated and computerized X-ray diffractometers are available for teaching and research: a GE-XRD-5 diffractometer and a Nicolet 12/V polycrystalline diffraction system. In addition, a variety of software has been developed to utilize these instruments effectively. Currently, background modeling, peak searching and curve fitting with deconvolution are in use for quantitative phase analysis and residual stress analysis. A search of the JCPDS Powder Diffraction File is provided with the Nicolet system. A variety of X-ray cameras and 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.

Metal Processing Institute (MPI)
http://www.wpi.edu/+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 several leading universities around the globe—Europe and Asia
• Graduate internship programs leading to a master’s 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 Web site: www.wpi.edu/+MPI.

MPI’s research programs are carried out by three distinct research consortia. These are described below:
• Advanced Casting Research Center (ACRC)
• Center for Heat Treating Excellence (CHTE)
• The Morris Boorky Powder Metallurgy Research Center (PMRC)
Materials Science and Engineering

**Advanced Casting Research Center (ACRC)**
http://www.wpi.edu/Academics/Research/ACRC/

The laboratory provides experimental facilities for course laboratories and for undergraduate and graduate projects. The laboratory is equipped with extensive melting and casting facilities, computerized data acquisition systems for solidification studies, thermal analysis units, liquid metal filtration apparatus, rheocasting machines, and a variety of heat treating furnaces. The laboratory has strong collaborations with industry, and students work directly with professional engineers from sponsoring companies. Forty-five corporate members participate in and support the ACRC research programs. Student scholarships offered by the Foundry Education Foundation (FEF) are available through the laboratory. The ACRC conducts workshops, seminars and technical symposiums for national and local industries. The laboratory is available throughout the year for project activity and thesis work as well as co-op and summer employment. Project opportunities at international sites are also available through ACRC/PMRC.

**Center for Heat Treating Excellence (CHTE)**
http://www.wpi.edu/Academics/Research/CHTE/

The center is an alliance between the industrial sector and researchers to collaboratively address short-term and long-term needs of the heat treating industry. It is the center’s intent to enhance the position of the heat treating industry by applying research to solve industrial problems, and to advance heat treatment technology. The center’s objective is to advance the frontiers of thermal processing through fundamental research and development.

Specifically, the center will pursue research to develop innovative processes to:
- Control microstructure and properties of metallic components
- Reduce energy consumption
- Reduce process time
- Reduce production costs
- Achieve zero distortion
- Increase furnace efficiency
- Achieve zero emissions

Over fifty corporate members participate in and support the CHTE research programs. MPI project opportunities, industrial internships, co-op opportunities and summer employment are available through CHTE/PMRC.

**The Morris Boorky 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 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 industry.
- Develop for graduate and undergraduate students course and project experiences that will foster an understanding of the industry.

Twenty-one corporate members participate and support the PMRC research programs. MQP project opportunities, industrial internships, co-op opportunities and summer employment are available through PMRC/PMRC.

**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 the following core courses: MTE 510, MTE 525, MTE 530, MTE 540, MTE 550 and MTE 560, two MTE or other 4000, 500 or 600 level engineering, science or mathematics electives, and 6 thesis credits. All courses must be 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 Program**
- Materials engineering core courses—18 credits
- Electives—6 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 ade-
quate 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.

**Faculty**

R. D. Sisson Jr., Professor of Mechanical Engineering; Director, Materials Science and Engineering Program; Ph.D., Purdue University

D. Apelian, Howmet Professor of Engineering; Director, Metal Processing Institute; Sc.D., Massachusetts Institute of Technology

I. Bar-On, 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, Saint Gobain Professor; Director, Manufacturing Engineering; Ph.D., University of Vermont

C. D. Demetry, Associate Professor; Ph.D., Massachusetts Institute of Technology

R. N. Katz, Research Professor; Ph.D., Massachusetts Institute of Technology

M. M. Makhlouf, Professor; Director, 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
Mathematical Sciences

Programs of Study
The Mathematical Sciences Department offers four programs leading to the degree of master of science, a Combined B.S./Master'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.

Master of Science in Applied Mathematics Program
This 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, mathematical materials science, 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 a related field, or for a career in industry immediately after graduation.

Master of Science in Applied Statistics Program
This 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. Of particular note are the statistical consulting course, which develops interpersonal and statistical consulting skills, and the Master's Project, which involves the solution of a large-scale real-world problem, often originating in industry, business or government. Through the selection of elective courses, the student may choose a program with an industrial emphasis or one with a more theoretical emphasis.

Professional Master of Science in Financial Mathematics Program
This program offers an efficient, practice-oriented track to prepare students for quantitative careers in the financial industry, including banks, insurance companies, and investment and securities firms. The program gives students a solid background and sufficient breadth in the mathematical and statistical foundations needed to understand the cutting edge techniques of today and to keep up with future developments in this rapidly evolving area over the span of their careers. It also equips students with expertise in quantitative financial modeling, and the computational methods and skills that are used to implement the models. The mathematical knowledge is complemented by studies in financial management, information technology and/or computer science. The bridge from the academic environment to the professional workplace will be provided by a professional master's project that involves the solution of a concrete, real-world problem directly originating from the financial industry. Students are encouraged to complete summer internships at financial firms. The department can help students to find suitable financial internships through the industrial connections of faculty affiliated with the Center for Industrial Mathematics and Statistics (CIMS), will help students identify and select suitable industrial internships. Graduates of the program are expected to start or advance their professional careers in industry.

Combined B.S./Master's Program
This program allows a student to work concurrently toward bachelor and master of science degrees in applied mathematics, applied statistics, financial mathematics and industrial mathematics.

Master of Mathematics for Educators
This is a 30-credit evening program designed primarily for secondary school mathematics teachers. Courses offer a solid foundation in areas such as geometry, algebra, modeling, discrete math and statistics, while also including the study of modern applications. Additionally, students develop materials, based on course work, which may be used in their secondary classes. Technology is introduced when possible to give students exposure for future consideration. Examples include Geometer's Sketchpad; Maple for algebra, calculus and graphics; Matlab for analysis of sound and music; and the TI CBL for motion and heat.

For teachers in the Massachusetts public schools, WPI may grant a professional license upon completion of the MME degree.

During the summers of 2002, 2003 and 2004, 3-credit courses in modeling of industrial projects are available, thanks to a grant obtained from the General Electric Fund.
Doctor of Philosophy in Mathematical Sciences Program
The goal of this 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, e.g., from industry or a national research center. The intention of this project is to connect theoretical knowledge with relevant applications and to introduce the candidate to potential employers.

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 modeling, turbulence and chaos, mathematical physics, mathematical biology, operations research, linear and nonlinear programming, discrete mathematics, graph 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 and model selection.

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-node (32 cpu) 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.

Center for Industrial Mathematics and Statistics (CIMS)
http://www.wpi.edu/~CIMS
The Center for Industrial Mathematics and Statistics was established in 1997 to foster partnerships between the University and industry, business and government in mathematics and statistics research. The problems facing business and industry are growing ever more complex, and their solutions often involve sophisticated mathematics. The faculty members and students associated with CIMS have the expertise to address today's complex problems and provide solutions that use relevant mathematics and statistics.

The Center offers undergraduates and graduate students the opportunity to gain real-world experience in the corporate world through projects and internships that make them more competitive in today's job market. In addition, it helps companies address their needs for mathematical solutions and enhances their technological competitiveness.

The industrial projects in mathematics and statistics offered by CIMS provide a unique education for successful careers in industry, business and higher education.

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 seven core courses: MA 503, MA 504, MA 508, MA 509, MA 510, MA 530, and either MA 512 or MA 514. 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 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 business, industry or academia. The remaining seven courses are normally chosen from the statistics/probability offerings of the Mathematical Sciences Department, courses numbered MA 542-556 plus MA 509. Upper-level undergraduate courses may be taken for graduate credit subject to the approval of the departmental Graduate Committee.

For the M.S. in Financial Mathematics
The Professional Master's Degree Program in Financial Mathematics is a 30-credit-hour program including a 3-credit-hour professional M.S. project originating from the financial industry. Students must take foundation courses MA 503 and MA 540, at least three from the four core financial mathematics courses MA 571, MA 572, MA 573 and MA 574, and two additional electives chosen from the graduate courses offered by the Mathematical Sciences Department.

A 6-credit block has to be completed in one of the following complementary areas outside of the Mathematical Sciences Department: financial management (e.g., from MG 501, MG 502, MG 509, MG 526 or MG 598), information technology (e.g., from MG 571, MG 573, MG 578 or MG 598) or computer science (e.g., from CS 504, CS 507, CS 531, CS 534, CS 542 or CS 552). Students with a degree or substantial work experience in one of the above complementary areas can substitute them with other courses subject to prior approval by the Graduate Committee. B.S./Master's students can count undergraduate credits for MA 4213, MA 4235, MA 4237, MA 4473 or MA 4632 toward electives, and suitable undergraduate courses toward the complementary area requirement.
Students shall participate in the Professional Master’s Seminars MA 562A and MA 562B. The Professional M.S. Project MA 598 involves solving a real-life problem originating in the financial industry. A student’s plan of study and the topic of the master’s project shall be approved by the Graduate Committee.

For the M.S. in Industrial Mathematics
The Professional Master’s Degree Program in Industrial Mathematics is a 30-credit-hour program. Students must complete four foundation courses: MA 503, MA 510 and two courses out of MA 508, MA 509 and MA 530. Students must also complete a 12-credit-hour module composed of two courses within the department and a sequence of two courses from one graduate program outside the Mathematical Sciences Department. The department offers a wide selection of modules to suit students’ interest and expertise.

In addition, students are required to complete a 3-credit-hour elective from the Mathematical Sciences Department and a 3-credit-hour master’s project on a problem originating from industry. Candidates are required to successfully complete the Professional Master’s Seminars MA 562A and MA 562B. The plan of study and the project topic need prior approval of the Graduate Committee.

Examples of Modules for the M.S. Degree in Industrial Mathematics
The courses comprising the 12-credit module should form a coherent sequence that provides exposure to an area outside mathematics and statistics, providing at the same time the mathematical tools required by that particular area. Examples of typical modules are:

- Dynamics and control module—MA 512, MA 540, ME 522 and ME 523 (or ME 527);
- Materials module—MA 512, MA 526, ME 531 and ME 532;
- Fluid dynamics module—MA 512, MA 526, ME 511 and ME 512 (or ME 513);
- Biomedical engineering module—MA 512, MA 526, BE/ME 554 and BE/ME 558;
- Machine learning module—MA 540, MA 541, CS 507 and CS 539;
- Cryptography module—MA 533, MA 514, CS 503 and EE 578.

For the Combined B.S./Master’s Programs in Applied Mathematics and Applied Statistics
A maximum of four courses may be counted toward both the undergraduate and graduate degrees. All of these courses must be 4000-level or above, and at least one must be a graduate course. Three of them must be beyond the 7 units of mathematics required for the B.S. degree.

Acceptance into the program means that the candidate is qualified for graduate school and signifies approval of the four courses to be counted for credit toward 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 (M.M.E.)
Candidates for the master of mathematics for educators 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.

Plan 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 or not 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 bachelor's degree is required for admission to all M.S. programs. A basic knowledge of undergraduate analysis, linear algebra and differential equations is assumed for applicants to the master's programs in applied mathematics and industrial mathematics. A strong background in mathematics, which should include courses in advanced analysis and linear algebra, is assumed for applicants to the master's program in financial mathematics. Typically, an entering student in the master of science in applied statistics program will have an undergraduate major in the mathematical sciences, engineering or a physical science; however, individuals with other backgrounds will be considered. In any case, an applicant will need a strong background in mathematics, which should include courses in undergraduate analysis and probability. Students with serious deficiencies may be required to correct them on a noncredit basis.

Candidates for the master of mathematics for educators degree must have a bachelor's degree and must possess a background equivalent to at least a minor in mathematics, including calculus and either teacher certification in mathematics or science or a full-time teaching position in one of these disciplines. Students are encouraged to enroll in courses on an ad hoc basis without official program admission. However, these students will not be eligible for any financial aid and must pay full tuition for each course. A typical student would complete the program in two years, taking one course each semester. However, the program can accommodate other completion schedules as well.

Faculty
B. Vernescu, Professor and Head; Ph.D. Institute of Mathematics, Bucharest, Romania
P. R. Christopher, Professor; Ph.D., Clark University
P. W. Davis, Professor; Ph.D., Rensselaer Polytechnic Institute
B. D. Doytchinov, Assistant Professor; Ph.D., Carnegie Mellon University
W. Farr, Associate Professor and Associate Head; Ph.D., University of Minnesota
J. D. Fehribach, Associate Professor; Ph.D., Duke University
J. Goulet, Coordinator, Master of Mathematics for Educators Program; Ph.D., Rensselaer Polytechnic Institute
A. C. Heinricher, Associate Professor; Ph.D., Carnegie Mellon University
M. Humi, Professor; Ph.D., Weizmann Institute of Science
J. H. Kimn, Visiting Assistant Professor; Ph.D., Courant Institute of Mathematical Sciences
C. J. Larsen, Assistant Professor; Ph.D., Carnegie Mellon University
C. Morales, Assistant Professor; Ph.D., Boston University
W. J. Martin, Associate Professor; Ph.D., University of Waterloo
B. Nandram, Professor; Ph.D., University of Iowa
D. Pasca, Visiting Assistant Professor; Ph.D., University of Bucharest
J. D. Petruccelli, Professor; Ph.D., Purdue University
M. Sarkis, Assistant Professor; Ph.D., Courant Institute of Mathematical Sciences
B. Servatius, Professor; Ph.D., Syracuse University
Mathematical Sciences

D. Shon, Visiting Assistant Professor; Ph.D., State University of New York at Stony Brook

A. W. Swift, Visiting Assistant Professor; Ph.D., George Washington University

D. Tang, Professor; Ph.D., University of Wisconsin

D. Vermes, Associate Professor; Ph.D., University of Szeged, Hungary

H. F. Walker, Professor; Ph.D., Courant Institute of Mathematical Sciences

S. Weekes, Assistant Professor; Ph.D., University of Michigan

A. H. Wiedie, Coordinator, Actuarial Mathematics Program; Ph.D., University of Massachusetts

J. Wilbur, Assistant Professor; Ph.D., Purdue University

V. Yakovlev, Visiting Associate Professor; Ph.D., Institute of Radio Engineering and Electronics, Russian Academy of Sciences

Emeritus

G. C. Branche, Professor
E. R. Buell, Professor
V. Connolly, Professor
W. J. Hardell, Professor
J. J. Malone, Professor

B. C. McQuarrie, Professor
W. B. Miller, Professor
Programs of Study
The Mechanical Engineering Department offers two graduate degree options:
• Master of Science
• 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, electric propulsion, multiphase flows, turbulent flows, fluid structure interactions, structural analysis, nonlinear dynamics and control, random vibrations, biomechanics and biomaterials, materials processing, mechanics of granular materials, laser holography, MEMS, computer-aided engineering systems, and engineering design.

The graduate curriculum is divided into five distinct areas of study:
• Fluids Engineering
• Dynamics and Controls
• Structures and Materials
• Design and Manufacturing
• Biomechanical Engineering

These areas are parallel to 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.

Students also receive credit for special topics under ME 593 and ME 693, and independent study under ISP. Faculty members often experiment with new courses under these designations, although no course may be offered more than twice in this manner. Except for certain 4000-level courses permitted in the B.S./M.S. program, no undergraduate courses may be counted toward graduate credit.

Mechanical Engineering Laboratories
The Mechanical Engineering Department at WPI provides a multidisciplinary research and education environment combining elements of mechanical engineering, manufacturing engineering and materials science. The facilities of the department are housed in the Higgins Laboratories and Washburn Shops.

Aerospace Laboratory
This laboratory includes a closed circuit, supersonic wind tunnel. This facility, with a test section approximately 2x2-foot cross section, is capable of speeds up to 60 mph. Another major element of this laboratory is a blow-down supersonic wind tunnel. It uses an evacuated tank for short intervals of time. Additionally, workshop areas are provided for model preparation and smaller scale experiment development.

Computational Gas and Plasma Lab (CGPL)
Research in CGPL entails the development of numerical simulation methods and modeling of non-equilibrium, multicomponent, multiscale, gaseous and plasma flows. A major research component involves the development continuum/atomistic simulation methods for micro- and nanoscale transport processes. Applications include spacecraft propulsion and micropulsion, spacecraft power, space environment/spacecraft interactions, microfluidics and nanofluidics. The computational research in CGPL is always conducted in close interaction with experiments. CGPL has been a participant in various national and international space programs. CGPL provides unique opportunities to graduate and undergraduate students with interests in aerospace applications or with interests in computational methods. Infrastructure at CGPL includes a Linux cluster for high-performance computing, peripherals, visualization and data reduction software.

Controls Laboratory
The Controls Laboratory, a 900-square-foot facility housed in Higgins Labs 248, is involved primarily with (1) the theoretical development, (2) the numerical implementation, and (3) the experimental verification and testing of intelligent control algorithms (adaptive, hybrid, switching, fault monitoring, on-line fault accommodation) for applications in structural, structural-acoustic, thermo-fluid and mechatronics systems.

Two vibration isolation tables (TMC 1163-573) and one active isolation table (TMC 63-563) are used to isolate test structure from ground vibration. Various piezoceramic patches (ACX QP20N) are bonded on structures to provide (moment) actuation. Four high-volt/low-amp single-channel (ACX-EL1224), a double-channel Krohn-hite (7602M) and one six-channel rack-mounted (PCB 790A06) power amplifiers are used to power piezoceramic actuators. For vibration measurements, five miniature (0.5g) ceramic shear ICP accelerometers (PCB U352C22) are available. A four-channel signal conditioner (PCB 442C04) with gain (x1,x10,x100) and one dual-mode vibration amplifier single-channel (PCB 443B01) are used to condition acceleration measurements.

Real-time data acquisition and control is realized through five dSPACE ACE-1104 (8 analog inputs, 8 analog outputs, 2 encoder inputs), one dSPACE ACE-1103 (8 analog outputs, 20 analog inputs, 6 encoder inputs), and one ACE 1102 (4 analog outputs, 4 analog inputs, 2 encoder inputs) stations. For signal generation and processing, five Instek function generators (3 MHz) and five Tektronix TDS2012 two-channel oscilloscopes are available, along with a Krohn-hite 3364 Low-pass/High-pass Butterworth/Bessel Filter. The laboratory supports both undergraduate and graduate research efforts.

Fluid Dynamics Laboratory
This laboratory provides experimental facilities and instrumentation for experimental activities in the area of fluid dynamics. A small, open-return subsonic wind tunnel, hot wire anemometry system, computer data acquisition systems and high-speed flow visualization systems are available. Separate areas are provided for model preparation and small-scale experiments.
Mechanical Engineering

Controls Laboratory
The Controls Laboratory housed in Higgins Laboratories is involved primarily with the theoretical development, the numerical implementation, and the experimental verification and testing of intelligent control algorithms (adaptive, hybrid, switching, fault monitoring, on-line fault accommodation) for applications in structural, structural-acoustic, thermofluid and mechatronic systems. The laboratory supports both undergraduate and graduate research efforts.

Hydrodynamics Laboratory
This laboratory provides experimental facilities and instrumentation for measurement of liquid flow phenomena. A closed-circuit free surface water tunnel with a 2x2-foot test section and vertical water tank are available. These facilities allow for flow visualization and are supported by data acquisition systems and various flow measurement devices.

Dynamic Simulation Laboratory (DYSIM Lab)
This is a general purpose PC laboratory that exposes large numbers of students to modern dynamic and geometric simulation techniques. Students use the DYSIM Lab to perform simulated experiments and observe demonstrations of course topics. The lab is equipped with 40 PCs that are connected through the computation network and direct links to other design process components.

Vibrations and Dynamics Laboratory
This facility houses equipment to support educational, project and research activities in the area of vibrations and controls. This is also a teaching laboratory for the development of analytical and experimental skills in modern engineering measurement methods, based on electronic instrumentation and computer-based data acquisition systems.

Center for Holographic Studies and Laser Technology (CHSLT)
CHSLT is used for both research and educational activities. The laboratory is equipped with several systems utilizing He-Ne, Ar-ion, and Nd:TAG Lasers.

The lab is supported by a self-contained network of computers and peripheral facilities, as well as supporting instrumentation systems. The lasers, computers and supporting instrumentation are used in studies of fundamental phenomena governing high-energy-density interactions in thin film imaging, with powder metal materials, plastics, ceramics and composites, micromachining, underwater propagation, holography, displacement and strain measurement, vibrations, fracture mechanics, mathematical modeling, numerical computations and applications to other problems of modern science, engineering and technology.

Keck Design Center – the Design Studios
These laboratories provide a prototype facility consisting of a design studio and a prototype production facility linked by computational equipment, and 20-30 high-end workstations with software support for video-picture-within-the-monitor teleconferencing to 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 around multiple workstations, and can 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.

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. The 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 areas 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.

Other Facilities
The following laboratories, located in the Washburn Shops, are described in the Manufacturing Engineering and Materials Science and Engineering program descriptions:

- Metal Processing Laboratory
  - Advanced Casting Research Center (ACRC)
  - Center for Heat Treating Excellence (CHTE)
  - Powder Metallurgy Research Center (PMRC)
- Ceramic/Powder Processing Laboratory
- Mechanical Testing Laboratory
- Optical and Electron Metallography Laboratories
- Polymer Engineering Laboratory
- HAAS Center for Computer-Controlled Machining
- Robotics Laboratory
- Surface Metrology Laboratory
- Computer-Aided Manufacturing Laboratory
M.S. Program
When applying to the master of science program, students must specify their intention to pursue either the thesis or non-thesis M.S. option. Both the thesis and non-thesis options require the completion of 30 graduate credit hours. Students in the thesis option must complete 12 credits of thesis research (ME 599), whereas students in the non-thesis option may complete up to 9 credits of directed research (ME 598). The result of the research credits (ME 599) in the thesis option must be a completed master’s thesis. The number of directed research credits (ME 598) completed in the non-thesis option can range from 0 to 9.

In the thesis option, the distribution of credits is as follows:
- 9 graduate credits in mechanical engineering
- 12 credits of thesis research (ME 599)
- 3 graduate credits in mathematics
- 6 graduate credits of electives within or outside of mechanical engineering

In the non-thesis option, the distribution of credits is as follows:
- 18 graduate credits in mechanical engineering (includes a maximum of 9 credits of directed research—ME 598)
- 3 graduate credits in mathematics
- 9 graduate credits of electives within or outside of mechanical engineering

Academic Advising
Upon admission to the M.S. program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. This plan must be made before the first registration. Prior to registering for additional credits, the student must specify an Academic Advisor with whom the remaining course of study is arranged. The plan must be approved by the mechanical engineering Graduate Committee.

For students in the thesis option, the permanent advisor is the Thesis Advisor. Prior to completing more than 18 credits, every student in the thesis option must form a Thesis Committee that consists of the Thesis Advisor and at least two other mechanical engineering faculty members from WPI with knowledge of the thesis topic.

The schedule of academic advising is as follows:
- Temporary Advisor—meets with student prior to first registration to plan the first 9 credits of study.
- Academic Advisor—selected by student prior to registering for more than 9 credits. For thesis option students, the Academic Advisor is the Thesis Advisor.
- Program of Study—arranged with Academic Advisor prior to registering for more than 9 credits.
- Thesis Committee (thesis option only)—formed prior to registering for more than 18 credits. Consists of the Thesis Advisor and at least two other mechanical engineering faculty members from WPI.

This schedule ensures that students are well advised throughout, and that students in the thesis option are actively engaged in their research at the early stages of their programs.

Thesis Defense
Each student in the thesis option 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 mechanical engineering 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 mechanical engineering 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.

Changing M.S. Options
Students in the non-thesis M.S. option may switch into the thesis option 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. Subject to the Thesis Advisor’s approval, directed research credits (ME 598) earned in the non-thesis option may be transferred to thesis research credits (ME 599) in the thesis option.

Any student in the thesis option M.S. program may request a switch into the non-thesis option by submitting the request in writing to the mechanical engineering Graduate Committee. Before acting on such a request, the Graduate Committee will require and seriously consider written input from the student’s Thesis Advisor. Departmental financial aid given to the thesis-option students who are permitted to switch to the non-thesis option will automatically be withdrawn. Subject to the approval of the Mechanical Engineering Graduate Committee, a maximum of 9 credits of thesis research (ME 599) earned by a student in the thesis option may be transferred to directed research credit (ME 598) in the non-thesis option.
Ph.D. Program

The course of study leading to the Ph.D. degree in mechanical engineering requires the completion of 90 credits beyond the bachelor's degree, or 60 credits beyond the master's degree. For students proceeding directly from B.S. degree to Ph.D. degree, the 90 credits should be distributed as follows:

- Course work:
  - Courses in M.E. (incl. Special Courses and ISP) 15 credits
  - Courses in or outside of M.E. 15 credits
- Dissertation Research (ME 699) 30 credits
- Other:
  - Additional course work 30 credits

**TOTAL 90 credits**

For students proceeding from master's to Ph.D. degree, the 60 credits should be distributed as follows:

- Course work:
  - (incl. Special Topics and ISP) 12 credits
- Dissertation Research (ME 699) 30 credits
- Other:
  - Additional course work 18 credits

**TOTAL 60 credits**

In either case, the result of the dissertation research must be a completed doctoral dissertation. Prior to admission to candidacy, a student may receive up to 18 credits of predissertation research under ME 698. Only after admission to candidacy may a student receive credit toward dissertation research under ME 699.

Academic Advising

Upon admission to the doctoral program, each student is assigned or may select a temporary advisor to arrange an academic plan covering the first 9 credits of study. This plan should be arranged before the first day of registration.

Prior to registering for any additional credits, the student must identify a permanent Dissertation Advisor who assumes the role of Academic Advisor and with whom a suitable dissertation topic and the remaining plan of study are arranged. Prior to completing 18 credits, the student must form a Dissertation Committee that consists of the Dissertation Advisor, at least two other mechanical engineering faculty members and at least one member from outside the department. These committee members should be selected because of their abilities to assist in the student’s dissertation research.

The schedule of advising is as follows:

- 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 Dissertation Advisor, at least two M.E. faculty and at least one 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 written exam intended to measure fundamental ability in three of the following five curriculum areas: fluids engineering, dynamics and controls, structures and materials, design and manufacturing, and biomechanical engineering. The three areas are selected by the student. The exam is given in January. For students who enter the program with a bachelor's degree, the exam must be taken after three semesters if they began their studies in the fall, and after two semesters if they began in the spring. For students who enter the program with a master's degree, the exam must be taken after one semester if they began in the fall, and after two semesters if they began in the spring. Students in the M.S. program who plan to apply for fall admission to the Ph.D. program are strongly advised to take the candidacy exam in January before that fall. The details of the examination procedure can be obtained from the mechanical engineering Graduate Committee.

Dissertation Proposal

Each student must prepare a brief written proposal and make an oral presentation that demonstrates a sound understanding of the dissertation topic, the relevant literature, the techniques to be employed, the issues to be addressed, and the work done on the topic by the student to-date. The proposal must be made within a year of admission to candidacy. Both the written and oral proposals are presented to the Dissertation Committee and a representative from the mechanical engineering Graduate Committee. The prepared portion of the oral presentation should not exceed 30 minutes, and 90 minutes should be allowed for discussion. If the Dissertation Committee and the Graduate Committee representative have concerns about either the substance of the proposal or the student's understanding of the topic, then the student will have one month to prepare a second presentation that focuses on the areas of concern. This presentation will last 15 minutes with an additional 45 minutes allowed for discussion. Students can continue their research only if the proposal is approved.

Dissertation Defense

Each doctoral candidate is required to defend the originality, independence and quality of research during an oral dissertation defense that is administered by an Examining Committee that consists of the Dissertation Committee and a representative of the mechanical engineering Graduate Committee who is not on the
Dissertation Committee. The defense is open to public participation and consists of a one-hour presentation followed by a one-hour open discussion. At least one week prior to the defense, each member of the Examining Committee must receive a copy of the dissertation. At the same time, an additional copy must be made available for members of the WPI community wishing to read the dissertation prior to the defense, and public notification of the defense must be given by the mechanical engineering graduate secretary. The Examining Committee will determine the acceptability of the student’s dissertation and oral performance. The Dissertation Advisor will determine the student’s grade.

The Combined Bachelor’s/Master’s Program
The Mechanical Engineering Department offers a B.S./Master’s program for currently enrolled WPI undergraduates. Students in the B.S./Master’s program may choose either the thesis or non-thesis M.S. option. The department’s rules for these programs vary somewhat from the Institute’s rules.

For students in the B.S./Master’s program, 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 and special topics courses), and none may be lower than the 4000-level. No extra work is required in the 4000-level courses. A grade of B or better is required for any course to be counted toward both degrees.

The application for the B.S./Master’s program must include a list of four courses that the applicant proposes to count toward both his/her 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 early part of the last term (usually D-term) of the junior year.

Acceptance into the B.S./Master’s 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 to the program.

Students in the B.S./Master’s program who choose the thesis M.S. option 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./Master’s program who complete their B.S. degrees in May and choose the thesis option are encouraged to begin their thesis research during the summer immediately following graduation.

A detailed written description of the B.S./Master’s program in mechanical engineering can be obtained from the mechanical engineering graduate secretary.

Admission Requirements
For the M.S. program, applicants should have a B.S. in mechanical engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.). The standards are the same for admission into the thesis and non-thesis options of the M.S. program. At the time of application to the master’s program, the student must specify his/her option (thesis or non-thesis) of choice.

For the Ph.D., a bachelor’s or master’s degree in mechanical engineering or in a related field (i.e., other engineering disciplines, physics, mathematics, etc.) is required.

The Mechanical Engineering Department reserves its financial aid for graduate students in the Ph.D. program or in the thesis option of the M.S. program.
Mechanical Engineering

Faculty

Gretar Tryggvason, Professor, Department Head; Ph.D., Brown University, 1985; Numerical modeling of multiphase flows; gretar@wpi.edu

Diran Apelian, Howmet Professor, Director of the Metals Processing Institute; Sc.D., Massachusetts Institute of Technology, 1971; Solidification processing, spray casting, molten metal processing, aluminum foundry processing, plasma processing and knowledge engineering in materials processing; dapelian@wpi.edu

Holly K. Ault, Associate Professor; Ph.D., Worcester Polytechnic Institute, 1988; Geometric modeling, mechanical design, CAD, kinematics, biomechanics and rehabilitation engineering; hault@wpi.edu

Isa Bar-On, Professor; Ph.D., Hebrew University of Jerusalem, 1984; Mechanical behavior of materials, fracture and fatigue of metals, ceramics and composites, reliability and life prediction, electronic packaging; ibaron@wpi.edu

Ronald R. Biederman, George F. Fuller Professor; Ph.D., University of Connecticut, 1968; Materials science and engineering, microstructural analysis, SEM, TEM, diffraction analysis; rrb@wpi.edu

John J. Blandino, Assistant Professor; Ph.D. California Institute of Technology, 2001; Fluid mechanics and heat transfer in microdevices, electric propulsion and plasm dynamics, plasma-assisted materials processing; blandino@wpi.edu

Christopher A. Brown, Professor and Director, Manufacturing Engineering Program; Ph.D., University of Vermont, 1983; Surface metrology, machining, fractal analysis, mechanics of skiing, tribology, axiomatic design, materials science, computational modeling in surface metrology; brown@wpi.edu

Eben C. Cobb, Visiting Assistant Professor; Ph.D., University of Connecticut, 1985; Design of high-speed precision equipment, dynamics of high-speed rotating equipment, smart structures, vibration control; eccobb@wpi.edu

Michael A. Demetriou, Associate Professor; Ph.D., University of Southern California, 1993; Control of intelligent systems, control of fluid structure interactions, fault detection and accommodation of dynamical systems, acoustic and vibration control; mdemetri@wpi.edu

Chrysante Demetry, Associate Professor; Ph.D., Massachusetts Institute of Technology, 1993; Nanocrystalline materials and nanocomposites, materials processing, grain boundaries and interfaces in materials; cdemetry@wpi.edu

Mikhail F. Dimentberg, Professor; Ph.D., Moscow Institute of Power Engineering, 1963; Applied mechanics, random vibrations, nonlinear dynamics, rotordynamics, mechanical signature analysis, stochastic mechanics; diment@wpi.edu

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Mustapha S. Fofana, Associate Professor; Ph.D., University of Waterloo, Canada, 1993; Nonlinear chatter dynamics, delay systems, CAD/CAM, CIM/Networked manufacturing systems; msofana@wpi.edu

Cosme Furlong, Assistant Professor; Ph.D., WPI, 1990; MEMS, nanotechnology, laser applications, holography, fiber optics, computer modeling of dynamic systems, cfurlong@wpi.edu

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Chrysante Demetry, Associate Professor; Ph.D., Massachusetts Institute of Technology, 1993; Nanocrystalline materials and nanocomposites, materials processing, grain boundaries and interfaces in materials; cdemetry@wpi.edu

Mikhail F. Dimentberg, Professor; Ph.D., Moscow Institute of Power Engineering, 1963; Applied mechanics, random vibrations, nonlinear dynamics, rotordynamics, mechanical signature analysis, stochastic mechanics; diment@wpi.edu

William W. Durgin, K.G. Merriam Professor, Associate Provost; Ph.D., Brown University, 1970; Aerodynamics, hydrodynamics, flow-induced vibrations, microgravity fluid dynamics, drag reduction, noise generation, heat transfer, flow measurement; wwdurgin@wpi.edu

Agshar Esmaeeli, Research Assistant Professor; Ph.D., University of Michigan, 1995; Multiphase flows, boiling and bubbly flows, numerical modeling, aemae@wpi.edu

Mustapha S. Fofana, Associate Professor; Ph.D., University of Waterloo, Canada, 1993; Nonlinear chatter dynamics, delay systems, CAD/CAM, CIM/Networked manufacturing systems; msofana@wpi.edu

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Raymond R. Hagglund, Professor; Ph.D., University of Illinois, 1962; Product reliability, safety analysis, mechanics, design; hagglund@wpi.edu

Allen H. Hoffman, Professor; Ph.D., University of Colorado, 1970; Biomechanics, biomaterials, biomedical engineering, rehabilitation engineering, biofluids and continuum mechanics; ahoffman@wpi.edu

Zhikun Hou, Associate Professor; Ph.D., California Institute of Technology, 1990; Vibration and control, structural dynamics, structural health monitoring, smart materials and adaptive structures, stochastic mechanics, solid mechanics, finite elements, earthquake engineering; hou@wpi.edu

Hamid Johari, Professor and Associate Department Head; Ph.D., University of Washington, 1989; Fluid mechanics, turbulent mixing, unsteady and buoyant flows, aerodynamics; hjohari@wpi.edu

Robert N. Katz, Research Professor; Ph.D., Massachusetts Institute of Technology, 1969; Materials science, ceramics, metal matrix composites, technology assessment, design with brittle materials, materials processing; katz@wpi.edu

Makhlof M. Makhlouf, Professor; Ph.D., Worcester Polytechnic Institute, 1990; Solidification of metals, heat, mass and momentum transfer in engineering materials problems, processing of ceramics materials; mmm@wpi.edu
Yong-Mo Moon, Assistant Professor; Ph.D., University of Michigan, 2000; Mechanisms and reconfigurable machinery design, design methodology, control, and mechanisms design; moon@wpi.edu

Robert L. Norton, Professor; M.S., Tufts University, 1970; Mechanical design and analysis, dynamic signal analysis, computer-aided engineering, computer-aided design, finite element method, vibration analysis, engineering design, biomedical engineering; rlnorton@wpi.edu

David J. Olinger, Associate Professor; Ph.D., Yale University, 1990; Fluid mechanics, aero- and hydrodynamics, fluid structure interaction, fluid flow control, chaos theory; olinger@wpi.edu

Ryszard J. Pryputniewicz, Professor; Ph.D., University of Connecticut, 1976; MEMS, laser applications, holography, fiber optics, computer modeling of dynamic systems, bioengineering; rjp@wpi.edu

Joseph J. Rencis, Professor; Ph.D., Case Western Reserve University, 1985; Boundary- and finite-element methods, computational mechanics; jjrencis@wpi.edu

Mark W. Richman, Associate Professor, Graduate Committee Chair; Ph.D., Cornell University, 1984; Mechanics of granular flows, powder compaction, powder metallurgy; mrichman@wpi.edu

Yiming (Kevin) Rong, Professor; Ph.D., University of Kentucky, 1989; Manufacturing processes, CAD/CAM, tooling and fixturing, computer-aided fixture design and verification; rong@wpi.edu

Brian J. Savilonis, Professor; Ph.D., State University of New York at Buffalo, 1976; Fluid mechanics, biofluid mechanics, fire modeling, heat transfer; bjs@wpi.edu

Satya S. Shivkumar, Associate Professor; Ph.D., Stevens Institute of Technology, 1987; Biomedical materials, materials processing, structure property relationships, plastics; shivkuma@wpi.edu

Richard D. Sisson, Jr., Professor and Director, Materials Science and Engineering Program; Ph.D., Purdue University, 1975; Materials process modeling and control, manufacturing engineering, corrosion, environmental effects on metals and ceramics; sisson@wpi.edu

John M. Sullivan, Jr., Professor; D.E., Dartmouth College, 1986; Design of computer-aided engineering systems, development of graphics tools and mesh generation, numerical analysis of partial differential equations; sullivan@wpi.edu
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 nonprofit 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.

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, dilute magnetic semiconductors, semiconductor superlattices, and polymer and biomacromolecule solutions.

Classical and quantum optics
Fourier optics, photon statistics, nonlinear optics, fiber optics, coherent states and squeezed states, photoacoustic spectroscopy, optical properties of rough surfaces and of thin metal films, metrology and design of optical instruments, laser spectroscopy of impurity ions in glasses, development of infrared fiber lasers, quasi-elastic 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 non-magnetic 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 nonlinear 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—Nonlinear optics, photorefractive materials, atom pipes
S. W. Pierson—Statistical mechanics, High-T superconductors, vortices
L. C. Lew Yan Voon—Solid state physics, super lattices in semiconductors
G. D. J. Phillips—Light scattering spectroscopy, biochemical physics, polymers
R. S. Quimby—Optical properties of solids, laser spectroscopy, fiber optics
L. R. Ram-Mohan—Field theory, many-body problems, solid state physics
C. Koleci—Physics education
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 requires 90 credit hours, 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.

Faculty

T. H. Keil, Professor and Department Head; Ph.D., University of Rochester
P. K. Aravind, Associate Professor; Ph.D., Northwestern University
N. A. Burnham, Associate Professor; Ph.D., University of Colorado
G. S. Iannacchione, Assistant Professor; Ph.D., Kent State University
S. N. Jasperson, Professor; Ph.D., Princeton University
C. Kolec, Assistant Professor; Ph.D., Yale University
L. C. Lew Yan Voon, Associate Professor; Ph.D., WPI
D. F. Nelson, Research Professor; Ph.D., University of Michigan
G. D. J. Phillies, Professor; D.Sc., Massachusetts Institute of Technology
S. W. Pierson, Associate Professor; Ph.D., University of Minnesota
R. S. Quimby, Associate Professor; Ph.D., University of Wisconsin, Madison
L. R. Ram-Mohan, Professor; Ph.D., Purdue University
A. Zozulya, Associate Professor; Ph.D., Lebedev Physics Institute