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# School of Engineering

**Dean:** Lester A. Gerhardt (Acting)

**Associate Deans:** Joe H. Chow (Acting), Richard N. Smith

**Director of Core Engineering:** Kevin C. Craig

**School of Engineering Home Page:** <http://www.eng.rpi.edu>

Rensselaer's School of Engineering is committed to technological excellence in integrating research and education and in educating for career success.

Outstanding leadership in innovative and progressive education is a Rensselaer hallmark. Rensselaer is renowned for producing visionary and versatile technological leaders with a superior reputation for their global impact. Solidly endowed with the fundamentals of math, science, and engineering as well as invaluable research, communication, and entrepreneurial expertise, Rensselaer engineering graduates demonstrate an exceptional propensity for practical application of their knowledge. In addition, the inclusion of a strong humanities and social sciences component within this broad education and a full spectrum of activities, both in and out of the classroom, enhance human relations skills and generate a commitment to ethical behavior and social responsibility.

Highly cognizant of the constant evolution in the field of engineering, Rensselaer is dedicated to continually enhancing and revitalizing its curricula and facilities. Evidence of this dedication is its initiatives in such emerging fields as information technology and biotechnology. Among these are the soon-to-be-completed biotechnology and interdisciplinary research building, the ongoing attraction of leaders in these fields to our already excellent engineering faculty, and the development of expanded opportunities for research within these and other developing fields at both the graduate and undergraduate levels.

Key to promoting such new initiatives, as well as enhancing traditional disciplines, is Rensselaer's world-class faculty, all of whom hold the highest attainable degree in their fields. In addition to being actively engaged in research and teaching, most also keep their finger on the pulse of the world through consulting or entrepreneurial endeavors.

Especially appealing to Rensselaer's exceptional faculty and students alike are its superlative laboratories and facilities that enable them to conduct outstanding research. These include studio classrooms that, in addition to being equipped with highly advanced interactive learning tools, provide the small comfortable environment that enhances the School of Engineering's personalized approach to teaching, maximizing student interaction among classmates and professors, and encouraging hands-on, collaborative projects.

Commitment to mobile computing and interactive delivery are also features that distinguish Rensselaer engineering programs from those at other universities. As noted in the Educational Programs and Resources section of this catalog, the Institute mandated that all undergraduate students have laptop computers as of the fall of 2002. This mandate was issued in recognition that the entire world is moving in the direction of near constant computer access. In addition, the program supports the interactive delivery initiative, in which lectures are combined with recitation, modeling, simulation, and laboratory exercises. Unlike the traditional professor-centered straight lecture format, interactive delivery centers on the students and allows them to interact with each other as well as the instructor. Through these new programs, students experience greater freedom, are no longer tied to a desk for their computing needs, and are prepared for what they will find in the real world.

Teamwork is yet another aspect of real-world engineering that Rensselaer cultivates through both its coursework and facilities. A prime example is the Institute's 11,000 square-foot O.T. Swanson Multidisciplinary Design Laboratory (MDL). This distinctive, first-class facility consists of a state-of-the-art design space, rapid prototyping and fabrication space, and a system integration space for both mechanical and electrical as well as electromechanical products. Here, students work in cross-disciplinary teams on a variety of industry- and service organization-sponsored and entrepreneurial projects, all with practical and real-life applications.

Augmenting the course experience for both undergraduate and graduate students is access to numerous research centers and computing resources. These include one of the largest Class 100 clean-room facilities on an academic campus, a 100-ton-g centrifuge, a linear accelerator (LINAC), the Advanced Manufacturing Laboratories, and the student-faculty shop. Engineering students use extensive interactive workstation facilities for studies in computer-aided design, analysis, and/or manufacturing. Taught and researched in the clean-rooms are integrated circuit and interconnect technology. The centrifuge is used for geotechnical research and is a state-of-the-art facility. The manufacturing laboratories provide students an opportunity to design and manufacture their own product to realistic specifications.

Other specialized and more discipline-oriented facilities include laboratories in areas such as fluidization, heat transfer, biochemical engineering, biomedical engineering, structures, earthquake engineering, image processing, plasma dynamics, mechatronics, microelectronics, microwaves, electron optics, electrical machines, electron microscopy and materials characterization, subsonic and supersonic flow, tribology, viscoelasticity, two-phase flow, mass spectrometry, and ion physics.

Sponsoring both undergraduate and graduate research are a variety of government (federal and state) agencies as well as private industry. As a result of focusing research on topics of significant commercial interest, Rensselaer, in relation to other major university engineering programs, has one of the largest fractions of support from private industry.

Rensselaer offers research opportunities in major interdisciplinary research centers, which primarily involve School of Engineering faculty and students. Among these centers are the Academy for Electronic Media, Center for Advanced Technology (CAT), the Center for Integrated Electronics (CIE), The Center for Nanotechnology Research, and the Scientific Computation Research Center (SCOREC). These centers are interdisciplinary, so that center projects include students from each of several curricula. For example, in the CIE, students from many departments (e.g., Physics; Materials Science and Engineering; Mechanical, Aerospace; and Nuclear Engineering; Electrical, Computer, and Systems Engineering; Chemical and Biological Engineering; and Civil and Environmental) are members of teams that conduct government- and industry-supported basic and applied research.

Projects currently under way include multilevel interconnects, chemical-mechanical polishing, polymers for interlevel dielectrics, compound semiconductors, and wireless manufacturing programs that employ flexible technologies and organizations, as well as improved communications to help solve manufacturing problems. Also world-renowned is SCOREC's simulation-based engineering approach in which state-of-the-art computers and numerical models are applied to problems of great societal need.

In addition to the major Institute centers, the School of Engineering conducts research in its own multidisciplinary centers. These include the Center for Infrastructure and Transportation Studies, the Center for Image Processing Research, and the Center for Multiphase Research. At the department level, the School offers seven additional centers: the Bioseparations Research Center, the Center for Services Research and Education, the Statistical Consulting Research Center, the Center for Glass Science and Technology, the Geotechnical Centrifuge Research Center, and the Flexible Manufacturing Center.

Substantial Rensselaer research is also conducted outside these major centers, some involving multiuniversity collaboration. These research centers complement the following seven academic departments: Biomedical Engineering; Chemical and Biological Engineering; Civil and Environmental Engineering; Decision Sciences and Engineering Systems; Electrical, Computer, and Systems Engineering; Materials Science and Engineering; and Mechanical, Aerospace, and Nuclear Engineering.

All departments offer both undergraduate and graduate curricula and degree programs in their fields.

## Degrees Offered and Associated Departments

<b>Aeronautical Engineering</b>	Mechanical, Aerospace, and Nuclear Engineering
<b>Biomedical Engineering</b>	Biomedical Engineering
<b>Chemical Engineering</b>	Chemical and Biological Engineering
<b>Civil Engineering</b>	Civil and Environmental Engineering
<b>Computer Systems Engineering</b>	Electrical, Computer Systems Engineering
<b>Decision Sciences and Engineering Systems</b>	Decision Sciences and Engineering Systems
<b>Electric Power Engineering</b>	Electrical, Computer, and Systems Engineering
<b>Electrical Engineering</b>	Electrical, Computer, and Systems Engineering
<b>Engineering Physics</b>	Mechanical, Aerospace, and Nuclear Engineering
<b>Environmental Engineering</b>	Civil and Environmental Engineering
<b>Industrial and Management Engineering</b>	Decision Sciences and Engineering Systems
<b>Manufacturing Systems Engineering</b>	Decision Sciences and Engineering Systems
<b>Materials Engineering</b>	Materials Science and Engineering
<b>Mechanical Engineering</b>	Mechanical, Aerospace, and Nuclear Engineering
<b>Mechanics</b>	Mechanical Aerospace, and Nuclear Engineering
<b>Nuclear Engineering</b>	Mechanical, Aerospace, and Nuclear Engineering
<b>Nuclear Engineering and Science</b>	Mechanical, Aerospace, and Nuclear Engineering
<b>Operations Research and Statistics</b>	Decision Sciences and Engineering Systems
<b>Transportation Engineering</b>	Civil and Environmental Engineering

## Overview of Undergraduate Programs

### Baccalaureate Program

In general, the Bachelor of Science program is intended for students seeking careers in engineering-related areas or as a basis for advanced study in fields other than engineering. To obtain a B.S. in an engineering field, students must fulfill the general requirements listed in the Academic Information and Regulations section of this catalog and satisfactorily complete the prescribed engineering curriculum. Certain courses, such as one-credit-hour nonengineering courses graded on a satisfactory/unsatisfactory basis or more than six credit hours of ROTC courses, cannot be applied toward the degree requirements. Also noteworthy is that courses in accounting, industrial management, finance, entrepreneurship, and personnel administration that are offered by the School of Management, as well as ROTC courses, will not satisfy the humanities and social sciences requirement, but may be taken as free electives.

Although many students enter at the freshman level and achieve all their education objectives at Rensselaer, a significant number find it accommodating and advantageous to enter at intermediate levels. Entrance into the engineering program is particularly attractive to graduates of two-year colleges. All such students enter with advanced standing and credit according to their credentials.

## Professional Program

For most students, specialization and determination of the degree program that matches their individual career goals takes place during the third year. At this point, a student may pursue either a fourth year for their Bachelor of Science (B.S.) degree in an engineering specialty or, if accepted by the Office of Graduate Education for the professional program, undertake a coherent program integrating advanced undergraduate and graduate study leading to the Master of Engineering (M.Eng.) degree in a specific field, and receiving a Bachelor of Science along the way. This professional program offers post-baccalaureate studies specifically intended as preparation for professional engineering practice. Graduates of other colleges and universities may be admitted with advanced standing (the Professional Program excepted) if they have appropriate accredited baccalaureate engineering degrees or the equivalent. Admission to a professional degree program is based on demonstration of adequate preparation and competence. The faculty in each curriculum judges qualifications for admission. Application should be made directly to the Office of Graduate Education.

## Engineering Core Curriculum

The core engineering program forms the base for all engineering curricula. In addition to providing a solid base for later specialization, it allows students who are undecided as to their choice of engineering field or discipline an opportunity to clarify their interests. Such students can, by using the electives in the first two years, sample various disciplinary offerings to aid in choosing which engineering field to pursue.

The core engineering curriculum in the general format is presented on the following pages. Specific curricula for each field of specialization are presented under the corresponding disciplinary headings for students who are certain of their disciplinary choices and wish to begin specializing earlier than the third year. Two kinds of programs are listed under each discipline: (1) a four-year baccalaureate program leading to the Bachelor of Science degree; (2) a professional program, taken in the fourth and fifth years, leading to the B.S. and M.Eng. degrees.

While undergraduates normally are not allowed to take graduate-level courses (levels 6000–9000) except by special permission of the instructor, a student admitted to the Professional School may be required to take certain courses in the 6000–9000 range and may elect other such courses with the approval of his or her adviser.

All School of Engineering students entering Rensselaer directly from high school begin their curricula with the core engineering program. The primary objective of this program is to provide students with a liberal education and to develop a broad scientific and technical foundation for their future specialization. This predisciplinary-specific program usually extends through the second but may extend into the third academic year. During this phase, the primary focus is on the foundations of engineering as a unified field. The foundation in mathematics, physics, chemistry, and biology, combined with the specified engineering sciences (e.g., strength of materials or thermal-fluids, etc.) satisfies basic technical knowledge requirements without regard to the intended field of specialization. In the humanities and social sciences area, courses not only enrich the student as an individual but also provide the perspective professionals need to make decisions that will affect society. The course Introduction to Engineering Design is intended to enhance the student's ability to apply knowledge resourcefully to resolve engineering problems.

The electives within the core engineering program, together with the required basic content, give each student the opportunity to refine his or her goals and develop a broad and solid foundation. Elective courses also allow undecided students to sample professionally oriented courses from several curricula so as to make a more enlightened choice of major. A student can also choose electives to provide a broader base or use them to focus on a particular field at an early stage. An imaginative student, with faculty counsel, can develop any number of creative study programs. It is also possible to major in one branch of

engineering and obtain a concentration in a second branch.

Students need not begin specializing in a particular area until the fourth semester of study. However, when choosing electives, students must consider that each engineering discipline requires certain courses be taken earlier as field (or discipline) prerequisites.

To provide proper guidance, each student is assigned a faculty adviser who is knowledgeable in core engineering matters and can help the student plan a program to best meet his or her educational and career objectives. Once a student identifies a specific curriculum to pursue, a new adviser, who is particularly aware of the opportunities for advanced study in this area, is assigned.

The combination of the core engineering program with the subsequent discipline-specific courses provides a coherent yet flexible curriculum that allows students to obtain an engineering education at all levels in multiple focus areas. The overall School of Engineering program is structured to permit students to select plans of study that fit their individual goals, aptitudes, and interests. It also enables students to enter and leave at points most appropriate to their individual plans and to facilitate entrance at intermediate levels in the undergraduate and graduate programs.

All elements of the curricula, including both core and discipline-specific courses, are under continuous review to ensure the application of new pedagogues and teaching methods and the introduction of courses covering the latest technological and computing and analysis advances. Topics such as quality, ethics, cultural sensitivity, safety, environmental impact, and contemporary issues related to science and engineering, are constantly integrated into curricula. Additionally included in Rensselaer engineering curricula is the topic of entrepreneurship. Through these efforts, Rensselaer ensures that leadership, interpersonal communications, teamwork, problem formulation, system synthesis, critical thinking, and problem-solving skills are practiced and enhanced.

To provide a clear picture of what prospective engineering students can expect in their first two years at Rensselaer, the core engineering program proceeds as follows:

### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1300	Engineering Processes <sup>1,2</sup> or	
ENGR-1200	Engineering Graphics and CAD <sup>1</sup> .....	1	ENGR-1310	Intro. to Engineering Electronics <sup>2</sup> .....	1
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
CHEM-1300	Chemistry Principles for Engineers....	4	PHYS-1100	Physics I.....	4
	Hum. or Soc. Sci. Elective .....	4		Science Elective.....	4
				Hum. or Soc. Sci. Elective .....	4

### Second Year

Fall		Credit hours	Spring		Credit hours
MATH-2400	Intro. to Differential Equations .....	4	ENGR-2040	Intro. to Engineering Design (with PDI) .....	4
PHYS-1200	Physics II.....	4		Engineering Elective .....	4
	Engineering Elective .....	4		Engineering Elective .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
CSCI-1190	Beginning C for Engineers .....	1			

<sup>1</sup> These required courses may be taken in either order.

<sup>2</sup> Depending on major

## Electives

In the core engineering curriculum, electives may be selected from, but are not limited to, the following list of suggested courses. However, in most engineering curricula, specific electives are required or recommended during the core engineering phase. Students should consult the curriculum information for their intended fields of specialization before selecting electives.

### Engineering Electives

		ECSE-2010	Electric Circuits
ENGR-2090	Engineering Dynamics	ECSE-2410	Signals and Systems
ENGR-2250	Thermal and Fluids Engineering I	ECSE-2610	Computer Components and Operations
ENGR-2350	Embedded Control		
ENGR-2530	Strength of Materials	MANE-2060	Aerospace Fundamentals
ENGR-2600	Modeling and Analysis of Uncertainty	DSES-2210	Production and Cost Accounting
ENGR-2830	Nuclear Phenomena for Engineering Applications		
		<b>Mathematics and Science Electives</b>	
ENGR-4300	Electronic Instrumentation	MATH-4800	Numerical Computing
ENGR-4750	Engineering Economics and Project Management	CSCI-1100	Computer Science I
		ENGR-1600	Materials Science for Engineers
CHME-2010	Material, Energy, and Entropy Balances	CHEM-2250	Organic Chemistry I

For a complete description of all engineering courses, see the Course Description section of this catalog.

## Special Undergraduate Opportunities

### Undergraduate Research Experience

At Rensselaer, involving undergraduates in real-world engineering research is of paramount importance. Through the Undergraduate Research Program (URP), described in the Educational Resources and Programs section of this catalog, undergraduates work directly with faculty and/or graduate students on projects requiring critical inquiries. These studies involve exciting areas of leading-edge technological research and have the potential to result in groundbreaking discoveries. Involvement in undergraduate research can be arranged strictly for the experience, for credit, or for pay. Students apply through direct contact with faculty seeking students via Web site or campus advertisements.

### Cooperative Education

Students may augment their academic course work with work experience through the Cooperative Education program. Studies and work assignments are scheduled after consultation with their curriculum adviser. Although many co-op students complete their academic program in four years, some delay graduation for a year to obtain additional work experience. Additional information on Rensselaer's Cooperative Education Program can be found in the Student Life section of this catalog under Career Development Center.

### Study Abroad/Exchange Programs

Rensselaer's School of Engineering advocates a voluntary international experience as an ideal means to promote a broad-based engineering education, develop the "citizen engineer," and provide undergraduate students with a global perspective. To facilitate such opportunities, the School has helped formulate and actively participates in the Global Engineering Education Exchange (Global E<sup>3</sup>) program.

Oriented primarily to undergraduate students, this program offers them the chance to spend one or two semesters at an international university which could be followed by an industrial internship in that country. Preferred timing for this experience is the junior year, and students normally apply in the fall or spring of their sophomore year.

Application involves completing forms regarding required courses or desired electives. The Institute for International Education, which administers this program, matches the student to a participating university based on that student's educational discipline requirements, cultural experience, and language background. The student continues to pay tuition at the home institution (Rensselaer) and continues to be covered by financial aid mechanisms, insurance, etc. However, the student pays room and board to the host institution. Consequently, except for travel expenses, students participating in this program should incur no additional costs.

Global E<sup>3</sup> offers students the chance to study and learn in the native language of the host country. Such opportunities, for example, are available in France, Germany, Italy, Spain, and Austria. Additional opportunities allow students to pursue foreign study opportunities at universities where the courses are presented and taught in English. These include the Technical University of Denmark, Budapest University of Hungary, and universities in the United Kingdom, Finland, Korea, Singapore, and Japan, among others. As a result, while students may benefit from knowledge of a foreign language, it is not a requirement for participation in this program. Refresher language instruction in French and German is usually given in the summer preceding the fall semester for those who have prior language experience and will be studying in the foreign language.

Approximately 30 U.S. universities and 70 universities in the rest of the world participate in the Global E<sup>3</sup> program. Included among these nations are: Australia, Austria, Denmark, Finland, France, Germany, Hungary, Italy, Japan, Korea, Mexico, Singapore, Spain, Sweden, and the United Kingdom. People interested in the program should contact Professor Lester A. Gerhardt, Acting Dean, at (518) 276-6203 or via e-mail at [gerhal@rpi.edu](mailto:gerhal@rpi.edu). The program's Web site can be found at <http://www.iie.org/pgms/global-e3>.

Additional opportunities designed for the Rensselaer population in general are also available. Information on these opportunities can be found in the Educational Programs and Resources section of this catalog.

## Overview of Graduate Programs

In preparing students to reach the pinnacle of their expertise within their chosen profession, the School of Engineering's graduate programs strive to:

- Develop students' skills for conceiving, conducting, and communicating creative thought through advanced study in the classroom and inquiry-based independent and collaborative original research.
- Deepen students' knowledge while refining their ability to think critically and nurturing their ability to identify new areas for expanding knowledge and transferring it to application and practice.

The School of Engineering offers four graduate degrees through which students may achieve these objectives. These include the Master of Science (M.S.), Master of Engineering (M.Eng.), Doctor of Engineering (D.Eng.), and Doctor of Philosophy (Ph.D.) degrees.

### Master's Programs

Both the M.S. and M.Eng. degree programs focus on engineering fundamentals at advanced levels, and both include significant elective opportunities that permit students to individualize their study plans. Either program provides an excellent basis for further graduate work in engineering, and neither includes a foreign language requirement.

The Master of Engineering program is designed primarily for students preparing for professional practice and does not require a thesis. Admission is based on the student's demonstration of adequate preparation

and competence. Applications for admission should be transmitted to the Office of Graduate Education. Note that many students complete a Master of Engineering and then pursue a Ph.D.

The Master of Science program encompasses diverse educational needs and is designed primarily for students intending to obtain a Ph.D. degree. Admission requires a baccalaureate degree in an area appropriate to the individual's proposed plan of graduate study, and could conceivably be outside the field of engineering. Those who do not have a B.S. in Engineering, however, may be required to complete some extra course work that does not qualify for graduate credit. Depending on the department in which the degree is being pursued, a thesis may be required.

### **Doctoral Programs**

A doctoral student formally affiliates with the department where activities most closely relate to his or her advanced study goals. However, the range of inquiry may cut across department and school lines, so that research opportunities are extremely broad, and students can pursue highly individualized programs. There are no foreign language requirements.

The Doctor of Engineering degree is characterized by the special nature of the thesis. Thus the student, working with an adviser, proposes an engineering problem of substance and develops a solution. The student must demonstrate ability to apply scientific principles to meet engineering needs, with due regard to social and economic factors and within a reasonable time constraint. The presentation and defense of his or her conclusions before a doctoral subcommittee and guests serves as the final examination for the degree.

The Doctor of Philosophy program is the traditional degree with a thesis that involves substantial original research. The program follows the general rules of the Office of Graduate Education.

## **Biomedical Engineering**

**Chair:** Robert L. Spilker

**Department Home Page:** <http://www.bme.rpi.edu/>

Biomedical engineers are typically involved in research and design. They discover new knowledge that they apply to designing new engineering devices and systems for the fields of medicine and biology. Among the devices that biomedical engineering (BME) has produced are noninvasive body imaging systems, critical-care monitoring instruments used in intensive care units, and a wide spectrum of implants, such as artificial joints, oral implants, and vascular grafts, all of which are used to replace diseased tissues. With new discoveries related to stem cells, genomics, and proteomics, BME is becoming increasingly involved in cellular and molecular biology for basic research and design of new devices and technologies. For instance, many biomedical engineers are helping to advance the new field of tissue engineering. In this capacity, they use basic knowledge about the cellular/molecular processes of tissue regeneration to help design replacement tissues and organs. At Rensselaer, a key focus is functional tissue engineering, which encompasses the biology and engineering necessary to understand, characterize, synthesize, and shape the requisite mechanical behavior of living tissues.

Founded upon a strong engineering base, the BMED curriculum combines significant life science content with courses that bring engineering solutions to medical needs. BMED students may select a mechanical or materials concentration to develop knowledge and skills in cell and tissue engineering or implant design.

## Research Innovations and Initiatives

### Cell and Tissue Engineering

Cultured mammalian cells are used to study, *in vitro* and at the molecular level, systems of biomedical interest. Experimental projects in progress include investigations of the mechanisms of osteoblast interactions with orthopedic/dental implant materials; structure and biochemistry of the cell/biomaterial interface; the effects of mechanical stresses on cellular function, morphology, and structure; and the development of engineered tissues to repair or replace damaged tissues. Theoretical approaches are used in modeling proliferation of anchorage-dependent, contact-inhibited cells, and in quantifying morphological responses of cells to mechanical forces.

### Computational Bioengineering

The level of complexity inherent in the study of human systems such as musculoskeletal or cardiovascular systems frequently dictates the need for numerical solution methods. Rensselaer is developing and applying high-performance computational methods to the study of diarthrodial joint mechanics, cardiovascular mechanics, dental mechanics, and imaging. Projects involving the development of computational methods for bioengineering applications are done in collaboration with Rensselaer's Scientific Computation Research Center, as well as the Center for Subsurface Sensing and Imaging Systems (CenSISS).

### Orthopedic Biomechanics

In an aging individual, musculoskeletal well-being is a key factor that contributes towards quality of life. The Orthopedic Biomechanics Laboratory uses a combination of cellular and tissue-level approaches to (1) identify changes in the biological and mechanical characteristics of skeletal tissues with emphasis on aging and osteoporosis; and (2) develop microenvironments conducive to regeneration of lost or damaged matrix. Current research areas include biology and mechanics of hard tissue, cellular control of tissue growth and development, mechanobiology of skeletal tissue regeneration, and fatigue fractures of long bones.

### The Bone-Implant Interface

In oral/maxillofacial surgery, orthopedic surgery, and tissue engineering, events at the bone-implant interface ultimately determine clinical implant performance. All such interfaces transmit loads, so interfacial biomechanics and biomaterials become extremely relevant. Continuing projects include (1) characterization of applied forces and moments on oral implants *in vivo*, and (2) assessment of bone biology at loaded versus unloaded bone-implant interfaces. New aspects of these projects include digital image-based strain analysis of interfaces and cellular/molecular-level approaches to understand interfacial bone healing and remodeling under the influence of interfacial biomechanics and biomaterials.

### Other Research

Biomedical engineering research at Rensselaer involves three schools within the Institute and interactions with Albany Medical College, the University of Pennsylvania, Columbia University, Université de Montreal, UC San Francisco, Center for Tissue Integrated Prostheses (Spokane, Wash.), and several other hospitals.

## Faculty\*

### Professors

- Bizios, R.**—Ph.D. (Massachusetts Institute of Technology); cellular bioengineering, cell/biomaterial interactions, biomaterials.
- Brunski, J.B.**—Ph.D. (University of Pennsylvania); dental biomechanics and implants, bone healing at interfaces, biomaterials.
- Newell, J.C.**—Ph.D. (Albany Medical College); cardiopulmonary physiology, systems modeling, impedance imaging.
- Roysam, B.**—D.Sc. (Washington University); electrical, computer, and systems engineering; intelligent imaging at low SNR; parallel computation; biomedical applications.
- Spilker, R.L.**—Sc.D. (Massachusetts Institute of Technology); computational mechanics and biomechanics (department chair).
- VonMaltzahn, W.W.**—Ph.D. (University of Hannover, Germany) bioinstrumentation, physiological measurements and modeling.

### Associate Professors

- DePaola, N.**—Ph.D. (MIT-Harvard Medical School); biofluid mechanics, cellular bioengineering.
- Xu, G.X.**—Ph.D. (Texas A&M University); environmental health physics, health and medical physics, Monte Carlo simulations, anatomical modeling, biomedical use of radiation.

### Assistant Professors

- Plopper, G.**—Ph.D. (Harvard University Medical School); extracellular matrix and tissue engineering.
- Stegemann, J.P.**—Ph.D. (Georgia Institute of Technology); cell and tissue engineering, vascular biology, extracellular matrix biology.
- Thompson, Deanna M.**—Ph.D. (Rutgers University); tissue engineering (neural), microfluidics, microelectro-mechanical systems (MEMS).
- Vashishth, D.**—Ph.D. (University of London, UK); orthopedics biomechanics, hard tissue biology (aging and osteoporosis), sports medicine (stress fractures and running injuries), skeletal tissue regeneration.

### Affiliated Faculty

- Cheney, M.**—Ph.D. (Indiana University); professor of mathematical sciences; applied mathematics, differential equations, mathematical computed tomography.
- Doremus, R.D.**—Ph.D. (University of Illinois, University of Cambridge); professor of glass and ceramics science; physical chemistry, solutions of polyelectrolytes and proteins.
- Isacson, D.**—Ph.D. (New York University); professor of mathematics and computer science; electric current computed tomography.

### Adjunct Faculty

- Bowser, S.S., Jr.**—Ph.D. (University at Albany); cell structure and function, particularly cell motility and cytoskeleton-membrane interactions, effects of mechanical forces on cell physiology, biology of benthic foraminifera.
- Cousins, J.R.**—Ph.D. (Johns Hopkins University); magnetic resonance imaging and spectroscopy.
- Del Vecchio, P.J.**—Ph.D. (Fordham University); biology, vascular endothelium.
- Edic, P.M.**—Ph.D. (Rensselaer Polytechnic Institute); electrical impedance imaging and magnetic resonance imaging computation.
- Feustel, P.**—Ph.D. (Albany Medical College); cerebral circulation and respiration regulation.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

- Flaherty, L.**—Ph.D. (Cornell University Medical College); molecular genetics; mammalian genetics.  
Director, Genomics Institute, Wadsworth Center of the NYS Dept. of Health.
- Jacobs, R.L.**—M.D. (State University of Iowa); orthopedics, physiology, bone biochemistry.
- Lee, B.Y.**—M.D. (Seoul National University School of Medicine); surgical research, peripheral vascular surgery.
- Metzger, D.**—Ph.D. (University of Illinois at Chicago); regulation of immunity, mucosal immunology, immune response to xenogeneic tissue implants.
- Rizzo, V.**—Ph.D. (New York Medical School) Assistant Professor, The Center for Cardiovascular Sciences, Albany Medical College. Mechano-chemical signaling in endothelial cell canelae.
- Rangert, B.**—Ph.D. (Chalmers Institute of Technology); dental implants, biomaterials, biomechanics.
- Singer, H.**—Ph.D. (University of Virginia); vascular smooth muscle cell biology, calcium/calmodulin-dependent protein kinases, intracellular regulation of smooth muscle contractility.
- Turner, J.N.**—Ph.D. (State University of New York, Buffalo); biophysics, anatomic pathology, quantitative light microscopy.
- Emeritus Faculty**
- Ostrander, L.E.**—Ph.D. (University of Rochester); information processing, biomedical signal analysis, human factors in medical equipment design.
- Roy, R.J.**—M.D. (Albany Medical College), D.Eng.Sci. (Rensselaer Polytechnic Institute); systems physiology, digital signal processing, pattern recognition.
- Zelman, A.**—Ph.D. (University of California, Berkeley); membrane transport phenomena, food processing.

## Undergraduate Programs

### Objectives of the Undergraduate Curriculum

The Biomedical Engineering Department's baccalaureate program will:

- Provide students with a solid foundation in mathematics and computation and in the biological and physical sciences.
- Train students in the application of the engineering problem-solving skills of analysis, modeling, and simulation to current problems in medicine and biology.
- Train students in engineering design of biomedical products, processes, and systems.
- Provide students with specialized technical expertise to prepare for industrial, academic, or other careers in biomedical engineering.
- Develop students with strong written and oral presentation skills, as well as the ability to lead and contribute to multidisciplinary teams in industrial, academic, and clinical environments.
- Provide students with a broad learning experience, including the study of the humanities and social sciences, with an emphasis on ethics and social responsibility.
- Prepare students for life-long learning using interactive studio environments and modern learning cycle strategies.

Students may achieve these objectives through completion of the baccalaureate program leading to the B.S. degree. To ensure selection of the appropriate concentration and courses to meet individual interests and goals, students should consult their academic adviser as early as possible.

## Baccalaureate Program

In lieu of the general core engineering program presented earlier, students who identify biomedical engineering as their discipline may follow the program outlined below. This curriculum requires a minimum of 126 credit hours.

### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1200	Engineering Graphics and CAD .....	1
CHEM-1300	Chemistry Principles for Engineers....	4	ENGR-1600	Materials Science for Engineers <sup>3</sup> .....	4
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
ENGR-1330	Intro. to BME <sup>1</sup> .....	1	PHYS-1100	Physics I.....	4
	Hum. or Soc. Sci. Elective <sup>2</sup> .....	4		Hum. or Soc. Sci. Elective <sup>2</sup> .....	4

### Second Year

Fall		Credit hours	Spring		Credit hours
ENGR-2050	Intro. to Engineering Design .....	4	BMED-2200	Dynamic Systems for Biomedical Engineering .....	4
MATH-2400	Intro. to Differential Equations .....	4	CSCI-1100	Computer Science I .....	4
PHYS-1200	Physics II.....	4		Concentration I <sup>4</sup> .....	4
	Hum. or Soc. Sci. Elective <sup>2</sup> .....	4		Hum. or Soc. Sci. Elective <sup>2</sup> .....	4

### Third Year

Fall		Credit hours	Spring		Credit hours
BIOL-4290	Human Physiological Systems.....	4	ENGR-2600	Modeling Analysis of Uncertainty .....	3
	Concentration II <sup>5</sup> .....	4	BMED-4500	Advanced Systems Physiology .....	4
	Concentration III <sup>5</sup> .....	4		Concentration V <sup>5</sup> .....	4
	Concentration IV <sup>5</sup> .....	4		Concentration VI <sup>5</sup> .....	4
				Professional Development II <sup>7</sup> .....	2

### Fourth Year

Fall		Credit hours	Spring		Credit hours
BMED-4010	Biomedical Engineering Lab .....	4	BMED-4600	BME Design <sup>8</sup> .....	3
	Hum. or Soc. Sci. Elective <sup>2</sup> .....	4		Concentration VII <sup>5</sup> .....	4
	Free Elective I <sup>6</sup> .....	3		Free Elective III <sup>6</sup> .....	3–4
	Free Elective II <sup>6</sup> .....	3–4		Free Elective IV <sup>6</sup> .....	3–4
			ENGR-4010	Professional Development III .....	1

<sup>1</sup> ENGR-1330 or ENGR-1310 or ENGR-1300 may be taken in the first or second year.

<sup>2</sup> Placement of humanities and social science electives can be varied with free electives. The courses counted as free electives must show a minimum of 12 credit hours. The total credit hours for the degree is 126–128.

<sup>3</sup> Science requirement.

<sup>4</sup> For both the materials/mechanics concentrations, choose ENGR-2250.

<sup>5</sup> BMED specified concentration courses (see listing p. 141). Check prerequisites to assure that courses are taken in appropriate order. Free electives may be moved to different semesters to accommodate timing of concentration courses.

<sup>6</sup> The minimum total credit hours of free electives is 12, with no restrictions on the included number of 3 and 4 credit hour courses.

<sup>7</sup> Professional Development II will be fulfilled from a published list at the start of each semester and can be taken either semester; Professional Development III can be taken either semester of the senior year. Professional Development I is part of ENGR-2050.

<sup>8</sup> Capstone writing-intensive course.

### Concentrations

Biomedical Engineering offers two concentrations. Students interested in implant design, cell and tissue engineering, and computational biomechanics, for instance, may select a materials or mechanics concentration. For additional concentration courses, consult a department adviser. Course selections from these concentrations are given below and the typical sequence is designated by S2 for spring 2nd year; F3 for Fall 3rd year, etc.

#### **Materials Emphasis**

ENGR-2250 Thermal and Fluid Engineering I (S2)  
 MTLE-4100 Thermodynamics of Materials (F3)  
 MTLE-4030 Introduction to Glass Science (F3) *or*  
 MTLE-4050 Introduction to Polymers (F3)  
 BMED-4540 Biomechanics (F3)  
 BMED-4240 Tissue-Biomaterial Interactions (S3)  
 MTLE-2100 Structure of Engineering Materials (S3)  
 MTLE-4250 Properties of Engineering Materials II (S4)

#### **Mechanics Emphasis**

ENGR-2090 Engineering Dynamics (F3)  
 ENGR-2250 Thermal and Fluids Engineering I (S2)  
 ENGR-2530 Strength of Materials (F3)  
 BMED-4540 Biomechanics (F3)  
 BMED-4240 Tissue-Biomaterial Interactions (S3)  
 BMED-4650 Intro to Cell and Tissue ENGR (Fall)  
 MANE-4030 Elements of Mechanical Design (S4) *or*  
 ENGR-2350 Embedded Control (S4) *or*  
 MANE-4610 Vibrations (F4)

### Humanities and Social Sciences Electives

In this area, electives are based on the Institute and School of Engineering requirements. Students are urged to select humanities and social science sequences with adequate breadth and depth in subject areas. Students desiring minors in humanities or social sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

### Minor Programs

The Department of Biomedical Engineering offers a minor in biomedical engineering for undergraduates majoring in other engineering and science fields. The selection of courses must have the prior approval of the department and must form a coherent program. Below is a list of suggested courses for a minor in biomedical engineering.

#### **For Mechanical or**

#### **Materials Engineering Majors**

BMED-4010 Biomedical Engineering Laboratory  
 BIOL-4290 Human Physiology Systems  
 BMED-4500 Advanced Systems Physiology  
 BMED-4540 Biomechanics  
 BMED-4240 Tissue-Biomaterial Interactions

## Graduate Programs

The department offers programs leading to M.S., D.Eng., and Ph.D. degrees. Persons seeking admission to any of these graduate degree programs in biomedical engineering should have their Graduate Record Examination (GRE) aptitude test scores sent to Graduate Admissions Office. Applicants who cannot take the test should attach an explanation to the application. Submission of the GRE advanced test scores is also recommended. For further information on the GREs, write to Graduate Record Examinations, Box 955, Princeton, NJ 08541.

### Master's Programs

Rensselaer requires completion of at least 30 credit hours (with satisfactory grades) beyond the bachelor's degree. At least 15 of these credit hours must have suffix numbers 6000–6990.

#### Master of Science

The Biomedical Engineering M.S. degree can be obtained with or without a thesis. The latter option is recommended for students who do not plan further graduate studies. The thesis option is advised for students who plan to obtain a higher graduate degree. The master's thesis should contribute new knowledge to the field of study.

Students pursuing either M.S. option must complete a minimum of 30 credits. In consultation with the adviser, they must develop a plan of study that satisfactorily meets Institute requirements, core concentration requirements, and recommended technical electives. For students completing a thesis, at least 24 credits must be met in these requirements, and a maximum of six credits may be earned by thesis work.

#### Concentrations

At the M.S. level in Biomedical Engineering, programs of study fall into three different concentration areas:

##### *Biomaterials*

Engineering applications for the design of prosthetic devices such as implants or tissue-engineered constructs require sophisticated knowledge of the structure, properties, and behavior of a wide range of materials—metals, ceramics, glasses, polymers, composites, and biological materials. Implant design and the new field of tissue engineering involve a working knowledge of material properties, tissue-biomaterial interactions, and biocompatibility.

##### *Biomechanics*

Mechanics has helped solve problems involving cell physiology, blood flow, skin rheology, bone mechanics, load-bearing prostheses design, joint lubrication methods, and countless other items of interest in medicine. Continuum mechanics, finite element analysis, strain gauge techniques, model analysis techniques, and micromechanics are some of the methods used to attack these problems in biomechanics.

## Biomedical Engineering Requirements

In addition to the Biomedical Engineering core requirements, students must also meet the concentration and elective requirements.

### Core Requirements Credit hours

BMED-4010	Biomedical Engineering Lab I .....	4
BMED-4500	Advanced Systems Physiology* .....	4

### Biomaterial Concentration requirements Credit hours

DSES-6020	Design of Experiments (or an equivalent course) .....	3
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### Biomechanics Concentration requirements Credit hours

BMED-4540	Biomechanics .....	3
DSES-6020	Design of Experiments (or an equivalent course) .....	3

### Recommended technical electives for a BMED Biomaterials Concentration

BMED-6240	Tissue-Implant Interfaces	MTLE-4050	Introduction to Polymers
BMED-6290	Biomechanics of Hard Tissues	MTLE-6040	Principles of Crystallography and X-ray Diffraction
BMED-6500	Mechanobiology		
MTLE-6080	Electron Microscopy of Materials	MTLE-6830	Deformation of Materials and Rheology
MTLE-6150	Fracture of Solids		
BMED-6280	Biomechanics of Soft Tissues		

### Recommended technical electives for BMED Biomechanics Concentration

BMED-6240	Tissue-Implant Interfaces		Rheology
BMED-6280	Biomechanics of Soft Tissues	MANE-4330	Analytical Methods in Solid Mechanics I (recommended for the Ph.D. Track)
BMED-6290	Biomechanics of Hard Tissues		
BMED-6500	Mechanobiology		
MANE-4240	Introduction to Finite Elements	MANE-4340	Analytical Methods in Solid Mechanics II (recommended for the Ph.D. Track)
MANE-6660	Fundamentals of Finite Elements		
MTLE-6150	Fracture of Solids		
MTLE-6830	Deformation of Materials and	MANE-6180	Mechanics of Composite Materials

## Doctoral Programs

Matriculation into the doctoral program is based upon prior demonstration of a high level of academic achievement in graduate and/or undergraduate work. Advanced study and research are conducted under the guidance of a faculty member of the Department of Biomedical Engineering and an interdisciplinary committee. Usually 54 credits of formal courses are required in addition to the residency and thesis requirements. These requirements are formalized in a plan of study that is prepared in consultation with the research adviser and doctoral committee.

## Course Descriptions

Courses directly related to all Biomedical Engineering curricula are described in the Course Description section of this catalog under the department codes BMED, CHME, ECSE, MTLE, and MANE.

\* New graduate students entering BMED with no previous biological course work can take BMED-4290 as a background course, but in this case, this course is not counted in the credits for the master's or Ph.D. degree.

# Chemical and Biological Engineering

**Acting Chair:** B. Wayne Bequette

**Director, Industrial Liaison Program:** E. Bruce Nauman

**Department Home Page:** <http://www.eng.rpi.edu/dept/chem-eng/>

The chemical conversion of resources into new, more useful forms has been the traditional concern of chemical engineers. In recent years, a critical concern with the depletion of resources has developed, leading to increased efforts to conserve, recycle, and find alternatives. Concurrently, with high-technology advances in biochemical and semiconductor processing, these developments pose challenges that fall on the chemical engineering profession.

The major educational objective in the Howard P. Isermann Department of Chemical and Biological Engineering is to prepare students to enter their engineering practice dealing with chemical as well as physical processes to meet the challenges of the future. The curriculum, which builds on chemistry, mathematics, basic sciences, and engineering science, culminates in professional applications in which theory is tempered by engineering art and economic principles. Through this curriculum, graduates are prepared equally well for professional practice or for advanced study.

Opportunities for creative and satisfying practice in chemical engineering can be found in conception, design, control, or management of processes involving chemical change. These processes range from the more conventional conversion of crude oil into petrochemicals and plastics, to the microbiological transformation of hardwood chips into specialty alcohols, or to the creation of semiconductor devices from silicon wafers. Diverse career choices exist not only in the chemical industry, but in virtually all processing industries, including agricultural, biochemical, chemical, food, nuclear, semiconductor processing, and environmental operations. By avoiding specialization and emphasizing basic principles, the program prepares its graduates for positions spanning the spectrum of activities from research and development, to process and project engineering, to production, or to technical marketing.

## Research and Innovation Initiatives

### Fluid Mechanics

Projects in this area involve the mechanics of fluidized beds, spouted beds, bubbles, low Reynolds number hydrodynamics, kinetic theory, two-phase flow, and surfactant behavior in organic-aqueous systems.

### Heat Transfer

Topics of interest include free convection stability, forced convection (particularly in laminar flow systems), fluid-to-particle heat transfer in fluidized and spouted beds, and boiling. Studies on heat and mass transfer at interfaces are also under way.

### Mass Transport

Research is in progress on simultaneous heat and mass transfer in porous media; the effects of interfacial phenomena on mass transfer; diffusion and mixing in laminar flow systems; transient dispersion processes in capillaries, porous media and open channels; and crystal growth phenomena.

### Thermodynamics

Activities include molecular simulation, the analysis and correlation of phase-equilibrium data, the development and evaluation of fluid-phase equations of state, and the study of topics in solution thermodynamics.

### **Interfacial Phenomena**

Problems under investigation include interfacial resistance to mass transfer and the interaction between surface forces and interfacial convection. Work in the interfacial area is concerned with heat, mass, and momentum transfer in multicomponent, ultrathin, liquid films. Research includes studies on condensation and evaporation in the contact line region, distillation from ultrathin films, lubrication, surface-tension-driven instabilities in atomically clean liquid metals, pattern formation in dendritic growth, protein-solid interaction, and the design of biocompatible surfaces.

### **Biochemical and Biomedical Engineering**

Research projects in biochemical engineering emphasize biocatalysis, bioseparations, and metabolic engineering. Fundamental and applied aspects of enzyme technology, mammalian cell culture, membrane sorption and separation, displacement chromatography, and salt-induced precipitation are important areas of focus. New designs involving aqueous and nonaqueous enzyme technology are being developed, as are new types of membrane-entrapped-enzyme and animal-cell-suspension reactors, which are being built, tested, and analyzed. Metabolic engineering processes are being used to develop high-rate bacterial fermentations and overproducing hybridoma cultures for producing chemical intermediates and monoclonal antibodies, respectively. Control theory of biological processes and an optical biosensor for metal detection are also being pursued. Projects in biomedical engineering involve the design of polymeric inhibitors of bacterial toxins and viruses, and the use of microfabrication tools to modulate the interaction of mammalian cells with their environment for applications in tissue engineering.

### **Separation Processes**

The fundamentals of separating species, especially in dilute solutions, is the focus of ongoing experimental and theoretical research. Projects include the understanding of separation by membranes and the development of new membranes, adsorption and chromatographic separations for preparing laboratory quantities of unusual chemicals, and protein precipitation processes. Another major research program is the recycling of microelectronic etching solutions using membrane separation processes.

### **Molecular Simulations**

Monte Carlo and molecular dynamics simulations are being used in combination with statistical mechanical theories to understand thermodynamics, structure, and kinetics of biomolecules in aqueous solutions. Special emphasis is placed on understanding and relating water structure near different solutes and in different environments to resulting interactions (e.g., hydrophilic and hydrophobic interactions). Molecular simulation techniques are also being applied to polymeric systems to understand penetrant solubility and diffusivity in polymers.

### **Polymers**

A large polymer research program focuses on polymer reaction engineering including devolatilization and heat transfer. Current work emphasizes bulk polymerizations in tubular reactors and segregation phenomena in stirred tank reactors. Under study are ways of enhancing heat transfer to fluids in laminar flow and the application of polymer devolatilization technology to unconventional substances. The recovery of commingled scrap plastics by selective dissolution is a major activity. Other active areas include structure-property relationships, rheology, extrusion, and a large interdisciplinary program on biocatalysis in polymer synthesis and modification.

### **High-Temperature Kinetics**

The development of more efficient, less polluting, combustion systems, requires accurate chemical kinetic input data on individual reactions over large temperature ranges. Rensselaer is pioneering the development of experimental techniques for obtaining such data. This work includes design,

construction, experimentation, and the generation of data for use by reaction system modelers. Both fast-flow thermal and pseudostatic photochemical systems are used. Various light sources, such as lasers, combined with electro-optical detection techniques are employed to determine the time history of reactants. Larger reactants and products are observed mass spectrometrically. Microcomputers are used for experimental control and data handling. In some work, the light-emitting and electrical-charge generation aspects of reactions are also investigated. In addition to combustion, this work is important to technological fields, such as semiconductor processing, metals refining, and optical fiber and carbon black manufacturing, as well as models of the atmosphere. A better understanding of the temperature dependence of reaction rate coefficients is a significant result of this work.

### **Advanced Materials**

Research interests are centered on developing and understanding the phenomena involved in producing advanced materials for the optical, electronic, and allied industries. Thermodynamic, transport, and chemical processes governing the formation and subsequent behavior of these materials are under active investigation. Research areas include modeling and optimizing CVD-reactor-system designs for producing high-efficiency, epitaxial layers economically in an environmentally sound manner, and developing nonlinear and electro-optic inorganic and organic materials for switching and memory applications. Additional research areas are understanding phenomena involved in the production and use of microlens arrays, wave-guide lasers, and determining the composition, property, and structure relationships of crystalline and glassy materials.

### **Process Control and Design**

A major focus of this research is the development of realistic, robust control strategies for multivariable chemical processes having parameter and process uncertainties. Such strategies are created to exploit the dynamic properties inherent in the systems. Integration of the modeling, design, and control of specialty chemical and pharmaceutical processes is of particular interest.

### **Interdepartmental Research**

Several research areas involve participation and cooperation with other departments. Such areas include polymer studies with the Materials Science and Engineering and Chemistry Departments, fermentation and other biochemical research with the Biology Department, studies in fluid mechanics with the Mathematics Department, polymer membrane fabrication with the Chemistry Department, and research on lubrication and other interfacial phenomena with the Mechanical Engineering Department. Research into state-of-the-art design and optimization of CVD reactors for semiconductor production is conducted jointly with the Center for Integrated Electronics. Additional information on research in these areas is found in the catalog sections for those departments.

### **Research Related Facilities**

The department maintains extensive research and instructional laboratories which house myriad special and unique equipment developed for specific studies, as well as extensive analytical and optical instrumentation, minicomputers, and microcomputers. Major instrumentation such as a GC/mass spectrometer, an X-ray fluorescence analyzer, an ion chromatograph, HPLC systems, and a laser zee particle characterization system make Rensselaer's laboratories one of the most comprehensively equipped university centers for research in the areas described above. The Howard Isermann Biochemical Engineering Laboratory was established in the department exclusively for conducting biochemical engineering research. The department research programs also use a number of major university facilities including the electron optics laboratory and the polymer laboratories in the Materials Research Center.

## Faculty\*

### Professors

- Belfort, G.**—Ph.D. (University of California, Irvine); membrane sorption and separations engineering, biocatalysis, biosensors, magnetic resonance flow imaging.
- Bequette, B.W.**—Ph.D. (University of Texas, Austin); chemical process modeling, control, and optimization; biomedical and drug infusion systems.
- Bizios, R.**—Ph.D. (Massachusetts Institute of Technology); cellular bioengineering, cell/biomaterial interactions, biomaterials.
- Cale, T.S.**—Ph.D. (University of Houston); microelectronic materials processing and simulation.
- Cramer, S.M.**—Ph.D. (Yale University); biochemical engineering, chromatographic separations.
- Dordick, J.S.**—Ph.D. (Massachusetts Institute of Technology); biochemical engineering, enzyme technology, polymer chemistry, bioseparations.
- Glicksman, M.E.**—Ph.D. (Rensselaer Polytechnic Institute); transport phenomena of crystal growth.
- Hirsa, A.**—Ph.D. (University of Michigan); fluid mechanics, experimental gas dynamics.
- Kumar, S.K.**—Ph.D. (MIT) Synthetic and bio-polymers, nano composites and nanomaterials.
- Lahey, R.T., Jr.**—Ph.D. (Stanford University); two-phase flow and boiling heat transfer.
- Nauman, E.B.**—Ph.D. (University of Leeds, England); reaction engineering, dispersion theory, laminar heat transfer.
- Plawsky, J.L.**—Sc.D. (Massachusetts Institute of Technology); optical, nonlinear and electrooptic, crystalline, and glassy materials.

### Assistant Professors

- Garde, S.S.**—Ph.D. (University of Delaware); molecular simulation.
- Kane, R.S.**—Ph.D. (Massachusetts Institute of Technology); biomedical engineering, polymers, surfaces, nanomaterials.
- Martin, L.L.**—Ph.D. (University of California, Los Angeles) process systems engineering, design for waste minimization and pollution prevention.
- Sharfstein, S.T.**—Ph.D. (University of California, Berkeley); biochemical engineering, mammalian cell culture.

### Distinguished Research Professors

- Fonstijn, A.**—D.Sc. (University of Amsterdam, Netherlands); combustion, high-temperature kinetics, gas phase reactions, atmospheric chemistry.
- Gill, W.N.**—P.E., Ph.D. (Syracuse University); transient dispersion processes, reverse osmosis systems, crystal growth phenomena, surface-tension-driven flow.
- Wayner, P.C., Jr.**—Ph.D. (Northwestern University); heat transfer, interfacial phenomena.

### Adjunct Faculty

- Belfort, M.**—Ph.D. (University of California, Irvine); molecular biology.

### Emeritus Professors

- Abbott, M.M.**—Ph.D. (Rensselaer Polytechnic Institute); thermodynamics.
- Altwickler, E.R.**—Ph.D. (Ohio State University); air pollution control, atmospheric chemistry.
- Bungay, H.R., III**—P.E., Ph.D. (Syracuse University); water resources, biochemical engineering.
- Chung, C.I.**—Ph.D. (Rutgers University); polymer processing, polymer melt rheology, relaxation behavior in polymer solids.
- Littman, H.**—Ph.D. (Yale University); fluidization, fluid-particle systems.
- Muckenfuss, C.**—Ph.D. (University of Wisconsin); kinetic theory, transport phenomena.
- Van Ness, H.C.**—P.E., D.Eng. (Yale University); thermodynamics.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

## Undergraduate Programs

### Objectives of the Undergraduate Curriculum

Graduates of the Howard P. Isermann Department of Chemical and Biological Engineering will:

- Have a solid background in chemistry, mathematics, basic science and engineering science
- Have technical knowledge of fundamental chemical engineering concepts of balance equations, thermodynamics, transport phenomena, chemical reaction engineering, separations processes, and process systems engineering
- Be able to communicate technical material through written reports and oral presentations
- Apply chemical engineering principles and economic analysis to the synthesis of chemical processes and products. These complex problems require teamwork, and the ability of individuals to serve as leaders and contributors
- Be prepared equally for professional practice or further graduate study in chemical engineering and biological engineering.
- As with all engineering disciplines, be informed citizens, broadly educated in the humanities and social sciences.

Students may achieve these objectives through completion of either the baccalaureate program leading to the B.S. degree or the professional program leading to the M.Eng. degree. Both programs are described in detail below.

### Baccalaureate Programs

The chemical engineering program comprises a minimum of 37 courses, which include three free electives and three area electives: one in advanced chemistry, one in advanced chemical engineering, and one in a nonchemical engineering area. On completion of three years of the baccalaureate program, the student may continue to the fourth year or be admitted to the professional program. While individual variations may be made in the course sequence in consultation with a faculty adviser, all listed courses and elective credits in the curricula must be satisfactorily completed to qualify for the specified degrees. A program outline that indicates required courses and electives is provided below. The complete curriculum totals 128 credit hours.

#### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1
ENGR-1300	Engineering Processes <sup>1,2</sup> .....	1	ENGR-1600	Materials Science for Engineers .....	4
CHEM-1300	Chemistry Principles for Engineers....	4	MATH-1020	Calculus II .....	4
MATH-1010	Calculus I.....	4	PHYS-1100	Physics I.....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

#### Second Year

Fall		Credit hours	Spring		Credit hours
CHME-2010	Material, Energy, and Entropy Balances.....	4	CHME-2020	Energy, Entropy, and Equilibrium <sup>3</sup> ....	4
MATH-2400	Intro. to Differential Equations .....	4	ENGR-2600	Modeling and Analysis of Uncertainty .....	3
PHYS-1200	Physics II.....	4	CSCI-1190	Beginning C Programming for Engineers .....	1
	Hum. or Soc. Sci. Elective .....	4		Free Elective .....	4
				Hum. or Soc. Sci. Elective .....	4

<sup>1</sup> These required courses may be taken in either order.

<sup>2</sup> May be replaced by ENGR-1310.

<sup>3</sup> Includes Professional Development I.

**Third Year**

Fall		Credit hours	Spring		Credit hours
CHME-4010	Fluid Mechanics and Heat Transfer ..4		CHME-4020	Heat and Mass Transfer .....	3
CHEM-2210	Organic Compounds & Reactions ....4		CHME-4030	Chemical Process Dynamics and Control .....	4
	Free Elective .....	4	CHEM-4460	Microscopic Physical Chemistry.....	4
	Hum. or Soc. Sci. Elective .....	4	CHEM-4530	Modern Techniques in Chemistry .....	4
				Professional Development II <sup>4</sup> .....	2

**Fourth Year**

Fall		Credit hours	Spring		Credit hours
CHME-4040	Chemical Engineering Separations....	3	CHME-4050	Chemical Process Design .....	3
CHME-4150	Chem. Eng. Lab. I .....	2	CHME-4160	Chem. Eng. Lab. II .....	2
CHME-4500	Chemical Reactor Design .....	3	ENGR-4010	Professional Development III .....	1
	Free Elective .....	4		Engineering Elective .....	4
	Chemical Engineering Elective .....	3		Chemistry Elective.....	4

**Electives**

As is evident in the above outline, the B.S. program includes several types of electives, three of which are specifically designated. These designated electives are subject to the following constraints:

- The chemistry elective must be in advanced chemistry or in an advanced chemistry-related subject.
- The chemical engineering elective must be in chemical engineering or in an approved, advanced chemical engineering subject.
- The engineering elective cannot be a chemical engineering course; it must be at least 2000-level and contain four credits of engineering topics.

The curriculum clearance officer, who maintains a list of appropriate courses, must approve selection of these three constrained electives. The three free electives are completely unconstrained.

**Humanities and Social Sciences Electives**

In this area, the electives are based on the Institute and School of Engineering requirements. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

**Professional Program**

Students who, at the end of their third year, apply and are accepted to this program will complete ten additional courses beyond the baccalaureate degree and will be awarded the M.Eng. degree. This program is described in detail below.

**Graduate Programs**

The Chemical and Biological Engineering Department offers the Master of Science, the Master of Engineering, and the Doctor of Philosophy degrees, each of which is tailored to fulfill the varying educational needs of its graduate students.

All graduate programs offer flexibility. Students are advised to plan programs that use course choices and

<sup>4</sup> This course will be fulfilled from a list published at the start of each semester. It may be taken either semester in Year 3.

electives to obtain in-depth studies in one or more subspecialties of their degree majors. Cross-disciplinary studies using courses offered by other departments or schools at Rensselaer are encouraged.

In addition, all graduate degree programs are arranged individually, and students are encouraged to use electives to conduct intensive studies in one or more subdisciplines or specialties. The M.S. and Ph.D. programs are particularly flexible. However, each student's program must include the following courses:

- CHME-6570 Chemical and Phase Equilibria (Fall)
- CHME-6610 Mathematical Methods in Chemical Engineering I (Fall)
- CHME-6510 Advanced Fluid Mechanics I (Spring)
- CHME-6640 Advanced Chemical Reactor Design (Spring)

**Master's Programs**

The master's degree represents an intermediate level of academic preparation. It is often the optimal degree for careers in engineering design.

**Master of Science**

The M.S., which requires a thesis, may be used for professional entry, but is also well suited to students who wish to measure their ability to get a Ph.D. without commitment of extra time beyond that required for an M.S. A special optional master's program is available for this purpose.

For the M.S., 30 credits of graduate-level studies, including six credits for the thesis, are normally required. However, the thesis requirement may vary from three to nine hours at the discretion of the department. The 24 hours of approved course work must include at least 15 credits of 6000-level courses. A formal thesis defense is not required.

Students who wish to follow the optional master's program should plan to take the Ph.D. comprehensive examination during their second semester of full-time graduate studies. The examination may be taken a maximum of two times. Passing students may register for an additional three credits of CHME-6990 Master's Thesis, and formal course work requirements for the master's degree are reduced to 21 hours. The student also has the option of proceeding directly toward a Ph.D. without completing the master's thesis. This option will normally reduce the time required for a Ph.D. by about six months. Students who elect to proceed in this manner will receive an M.S. degree, with thesis requirements waived, after two years of satisfactory full-time study and acceptance of the dissertation proposal.

**Master of Engineering**

The M.Eng. degree involves formal course work only and does not require a thesis. This degree is awarded on completion of 30 credits of course work. For a student with an accredited B.S. degree in chemical engineering, the program includes the following:

	<b>Credit hours</b>
CHME-6510 Advanced Fluid Mechanics I .....	3
CHME-6570 Chemical and Phase Equilibria.....	3
CHME-6610 Math Methods in Chem. Eng. I .....	3
CHME-6640 Advanced Chemical Reactor Design. ....	3
Electives .....	18

Of the electives, at least two must be chemical engineering courses, and at least two must be nonchemical engineering courses. A feature of this M.Eng. program is the opportunity to concentrate in one of the subspecialties of chemical engineering. These areas include (but are not limited to) biological engineering, process systems engineering, materials engineering, and polymer engineering.

## Doctoral Programs

The Ph.D. degree represents the highest level of academic preparation. With it, a student can expect to maintain technical competence and contributions throughout a professional career. It is usually the preferred degree for research and development in industry and government and for teaching.

Within the Chemical and Biological Engineering Department, 90 credits of graduate-level studies, including the dissertation, are required for a Ph.D. The emphasis is on advanced study in a specialty with major focus on the dissertation. A doctoral student must pass a comprehensive examination, prepare a dissertation proposal and the dissertation itself, and present and defend the dissertation.

## Course Descriptions

Courses directly related to all Chemical and Biological Engineering curricula are described in the Course Description section of this catalog under the department code CHME.

# Civil and Environmental Engineering

**Chair:** George F. List

**Coordinator of Undergraduate Studies (Civil and Environmental Programs):** Simeon Komisar

**Coordinator of Graduate Studies (Civil Program):** Jacob Fish

**Coordinator of Graduate Studies (Environmental Program):** James (Chip) Kilduff

**Department Home Page:** <http://www.cce.rpi.edu>

Civil and environmental engineers are responsible for providing the world's constructed facilities and the infrastructure on which modern civilization depends. These facilities can be large and complex and require that the engineer be broadly trained and able to deal with the latest technologies.

Civil and environmental engineers focus on the analysis, design, construction, maintenance, and operation of large-scale physical systems. To ensure the proper construction and care of these complex systems and environments, Rensselaer civil and environmental engineers develop a full range of skills in design, analysis, fabrication, communication, management, and teamwork. The current rebuilding of the world's roads, bridges, water and sewer systems, and other physical facilities has heightened society's awareness of the profession and given it added prominence. The growing panoply of sensors, instrumentation, intelligent facilities, and new materials is also highlighting the high-tech character of the discipline, creating new educational challenges and redefining the skill set that civil and environmental engineers need to succeed.

At Rensselaer, civil engineering has a long and distinguished history. In 1835, the Institute became the first U.S. school to issue a civil engineering degree. Among its graduates are William Gurley (1839) and Lewis E. Gurley (1845) partners in W&LE Gurley, Troy, N.Y., one of the first manufacturers of precision surveying instruments. Other world-renowned Rensselaer civil engineering graduates include:

- Francis Collingwood, Jr. (1855), honored by civil engineering's Collingwood Prize
- Washington Roebling (1857), builder of the Brooklyn Bridge
- Seijiro Hirai (1878), a president of the Imperial Railways, Japan
- George Ferris (1881), designer of the Ferris wheel

- Milton Brumer (1923), construction manager for the Verrazano Narrows Bridge
- Werner Ammann (1928), former partner, Ammann and Whitney
- Clay Bedford, Sr. (1925), general supervisor of the construction of the Bonneville and Grand Coulee Dams
- Ralph Peck (1934), co-author with Karl Terzaghi of the internationally-known book *Soil Mechanics in Engineering Practice*

Today, Rensselaer civil and environmental engineers continue to be found at all levels in both private and public sectors throughout the world.

A long-standing tradition at Rensselaer is educational programs in environmental problem solving. An early contribution to this field was the water analysis work of William Pitt Mason (1874), the pioneer of such activities in the U.S. in the late 1800s. Edward J. Kilcawley, a Rensselaer civil engineering professor who introduced environmental engineering as an option in the mid-1940s and as degree program in the mid-1950s, contributed visionary environmental engineering concepts.

In addition to those in the Department of Civil and Environmental Engineering, there are faculty members with teaching and research interests in environmental problem solving in the Department of Chemical Engineering. The same is true in Departments of Biology, Chemistry, Earth and Environmental Sciences, and Mathematical Sciences, all of which fall within Rensselaer's School of Science.

## Research and Innovation Initiatives

### Earthquake Engineering (Civil)

Rensselaer's earthquake engineering research program is concerned with seismic analysis and design methodologies that mitigate the negative impact of earthquakes on buildings, bridges, and pipelines (water, sewer, gas, and oil). It also focuses on analytical relationships that support decision-making and advance the state of the art in design codes, a key to future sustainability and durability. In these areas, Rensselaer's earthquake engineering research is among the best in the world. The Institute has a major geotechnical centrifuge facility and is in the process of building a medium-scale shaker table. The geotechnical centrifuge facility, fourth largest in the U.S. and among the twenty largest in the world, brings significant pre-eminence to the Institute. Rensselaer was recently selected as one of ten sites that will receive long-term NSF support as part of the Network for Earthquake Engineering Simulation initiative. Of major import in future research will be model-based simulation (using the centrifuge to extend existing simulation models and create new multiscale models), Web-based teleobservation and teleobservation (especially of a new robotic arm being built in collaboration with faculty from Mechanical, Aerospace, and Nuclear Engineering), and wireless sensors, using MEMs and other microelectronic devices (e.g., to unobtrusively instrument experimental specimens).

### Structural Engineering (Civil)

Design and analysis of bridges, buildings, and other large-scale facilities; material selection and specification; structural technology selection; dynamic and static structural modeling and analysis; environmental loads on structures.

### Geotechnical Engineering (Civil)

Behavior of soils and foundations under cyclic and dynamic loads; design methods to accommodate natural and man-made vibrations; geostochastics; soil dynamics, stability of earth slopes, structures, and dams.

**Transportation Engineering (Civil)**

This area of research includes design, analysis, maintenance, and operation of transportation systems and facilities; intelligent transportation systems, especially highway networks, goods distribution systems, and transit systems; real-time, multiobjective network management and control, including route guidance and dynamic traffic assignment; signal control systems; network management strategies; multiobjective routing and scheduling; and logistics decision making under uncertainty.

**Computational Mechanics (Civil)**

Studies involve the development of automated finite element modeling techniques, adaptive analysis procedures, development of adaptive multiscale solution techniques, qualification and modeling of engineering idealizations for analysis and design, design systems using knowledge-base techniques, prototype systems for applications including discrete crack propagation, forging simulations, multiple-scale modeling of composite materials and electronic packages, and unsteady aerodynamics.

**Infrastructure Engineering (Civil)**

Under development are analytical methodologies and software tools for preservation, restoration, and renewal of large distributed systems such as roadways, bridges, pipelines, power distribution networks, and bridge and pavement management systems. Additional studies include remote sensing condition assessment, deterioration modeling and performance prediction, vulnerability assessment, risk analysis, reliability-centered maintenance, and capital investment planning.

**Pollutant Fate and Transport (Environmental)**

Research areas are assessment of pathogen loading and transport in water supplies and treatment systems, fate of hydrophobic organics in sediment, and environmental chemistry of PAHs.

**Water Treatment (Environmental)**

Researchers investigate the influence of natural organic matter properties and water chemistry on the formation of disinfection byproducts, understanding fouling mechanisms in the use of membrane processes in water treatment, membrane modifications for water treatment, adsorption processes and hybrid processes for removal of DBP precursors

**Waste Treatment (Environmental)**

Studies focus on aerobic and anaerobic biological treatment reactors for municipal and industrial wastes; high strength anaerobic waste treatment in fluidized bed bioreactors with energy recovery, nutrient removal systems, hazardous waste treatment reactors, biofilters.

**Site Remediation and Bioremediation (Environmental)**

Research areas include combined advanced oxidation and biological treatment for sediment and soil slurry systems, in-situ degradation of chlorinated organics in groundwater, and solid phase treatment reactors for soils, slurries, and municipal solid wastes.

**Environmental Systems (Environmental)**

Under investigation are adaptive optimal control of treatment reactors, molecular modeling in environmental chemistry, and structure activity relationships

**Research Facilities**

Rensselaer's centrifuge was commissioned in 1989 and began conducting physical model simulations of soil and soil structure systems subjected to in-flight earthquake shaking in 1991. In over a decade of successful operation, the facility has published results of some 360 earthquake-related model simulations,

served as the basis for 12 Ph.D. theses at Rensselaer and contributed to Institute faculty and student research as well as that of dozens of visiting scholars and outside users from the U.S., Asia, Europe, and Latin America. It has also provided data and research results to many people and organizations around the world. This centrifuge earthquake research has been conducted with two existing one-dimensional in-flight shakers, which can accommodate 90 kg and 400 kg payloads respectively.

The next-generation earthquake engineering capability for the Rensselaer centrifuge includes 1) a 2-D in-flight earthquake shaker (two prototype horizontal components) and associated 2-D laminar box container to allow for more realistic 2-D modeling; 2) a four degrees of freedom (4-D) robot capable of performing in-flight operations such as construction and excavation, pile driving, ground remediation, cone penetration, and static and cyclic loading tests without stopping the centrifuge; 3) a networked data acquisition system with Internet teleobservation/teleoperation capability, to be linked to the high-speed Rensselaer gigabit Ethernet backbone; 4) two high-speed cameras and image processing software; 5) development of a new generation of advanced and improved sensors capable of providing a better resolution of the measured model response; and 6) other equipment aimed at increasing the capability of the centrifuge to test a greater number and wider variety of earthquake engineering models.

A major upgrade in lab equipment and space for environmental engineering research and teaching has occurred through the establishment of the Keck Water Quality Laboratory, the National Science Foundation Environmental Colloid and Particle Laboratory, and the refurbishment of the Environmental Engineering Teaching Laboratory suite. Analytical equipment in these labs provides the capability for analysis and investigation of a wide variety of industrial processes, treatment processes, and polluted environments. This equipment gives students experience and expertise in treatability and toxicity studies, design and operation of bench-scale treatment systems, and investigation of a wide range of environmental quality parameters. The fate of specific compounds in the environment and in treatment processes can be analyzed by UV-VIS spectrophotometry, high pressure liquid chromatography, gas-liquid and gas chromatography with a number of specific and sensitive detectors, including electron capture, flame ionization, thermal conductivity, and mass spectral. Metals analyses by atomic absorption spectrophotometry and elemental analyses are also available. A complete suite of water quality monitoring equipment, field sampling systems, and geographical information system tools are available. Computational capabilities are widely accessible not only throughout the campus, but also in research laboratories, as well.

## Faculty\*

### Professors

**Dobry, R.**—Sc.D. (Massachusetts Institute of Technology); geotechnical engineering, soil dynamics, earthquake engineering, seismic analysis.

**Dvorak, G.J.**—Ph.D. (Brown University); mechanics of solids, composite materials and structures, fracture and fatigue.

**Feeser, L.J.**—PE., Ph.D. (Carnegie Mellon University); structures, computer applications and computer graphics, computer-aided design, structural optimization.

**Fish, J.**—Ph.D. (Northwestern University); computational mechanics, finite element methods, micromechanics, mathematical modeling.

**List, G.F.**—PE., Ph.D. (University of Pennsylvania); intelligent transportation systems, sensors, instrumentation and control, multiobjective.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

- O'Rourke, M.J.**—PE., Ph.D. (Northwestern University); structures, lifeline earthquake engineering, snow loading on structures.
- Shephard, M.S.**—Ph.D. (Cornell University); computational mechanics, parallel processing, adaptive finite element techniques, automatic mesh generation.
- Wallace, W.A.**—Ph.D. (Rensselaer Polytechnic Institute); decision support systems, the process of modeling, environmental management, disaster management.
- Zimmie, T.F.**—PE., Ph.D. (University of Connecticut); geoenvironmental engineering, geotechnical engineering, groundwater hydrology, flow through porous media, landfills, centrifuge modeling, geosynthetics.

#### **Associate Professors**

- Holguín-Veras, J.**—PE. Ph.D. (The University of Texas at Austin); intelligent transportation networks, intermodal transportation, transportation planning and modeling, transportation economics.
- Kilduff, J.**—Ph.D. (University of Michigan); physicochemical processes, separations and recovery processes in water and wastewater treatment, effects of adsorption and mass-transfer on pollutant fate and transport in natural systems, membrane processes for water quality control.
- Symans, M.**—Ph.D. (State University of New York at Buffalo); structural dynamics, earthquake engineering, seismic isolation and energy dissipation systems, structural vibration control.

#### **Assistant Professors**

- Han, Jung-In**—Ph.D. (University of Michigan); microbial molecular biology, bioremediation, bioavailability of hydrophobic contaminants, microbial communication (quorum sensing).
- Montoya, Lupita**—Ph.D. (Stanford University); indoor air quality, biological aerosols, health effects of aerosols, human exposure to air pollutants, environmental justice.
- Nyman, M.C.**—Ph.D. (Purdue University); fate and transport of hydrophobic organic contaminants in natural systems, environmental chemistry.
- Zeghal, M.**—Ph.D. (Princeton University); soil dynamics and geotechnical earthquake engineering, computational geomechanics, geotechnical system identification and seismic response monitoring, damage diagnosis and nondestructive evaluation, and seismic risk analyses.

#### **Research Professors**

- Clesceri, N.L.**—Ph.D. (University of Wisconsin); advanced waste treatment, environmentally sound manufacturing, sediment decontamination.

#### **Research Assistant Professor**

- Abdoun, T.**—Ph.D. (Rensselaer Polytechnic Institute); geotechnical engineering.

#### **Clinical Associate Professor**

- Komisar, S.J.**—Ph.D. (University of Washington); wastewater treatment, biological processes, solid waste management..

#### **Adjunct Faculty (Civil Program)**

- Dall, J.**—M.S. (Rensselaer Polytechnic Institute); structural engineering.
- Dunn, R.H.P.**—M.S. (Rensselaer Polytechnic Institute); geotechnical engineering.
- Floess, C.**—Ph.D. (Rensselaer Polytechnic Institute); geotechnical engineering.
- Kenneally, D.**—B.S. (Rensselaer Polytechnic Institute); highway engineering.
- O'Malley, D.**—M.S. (Central Missouri State University); traffic engineering.
- Griggs, F.**—D.E. (Rensselaer Polytechnic Institute); structural engineering.
- Reilly, J.**—Ph.D. (Rensselaer Polytechnic Institute); transportation systems.

**Adjunct Faculty (Environmental Program)**

**Esler, J.**—PE., B.S. (Manhattan College) industrial waste treatment.

**Hetting, L.**—PE., Ph.D. (Rensselaer Polytechnic Institute) water resources.

**Young, K.**—J.D. (Harvard Law School) environmental law.

## Undergraduate Programs

### Civil Engineering Curriculum

#### Objectives of the Undergraduate Curriculum

While certain objectives of an undergraduate education in engineering are common to all programs, there are subtle but important differences depending upon the student's chosen field. In this regard, the Department of Civil and Environmental Engineering Department's baccalaureate program in Civil Engineering will:

- Prepare students to be involved, global citizens with a broad appreciation of the key civil engineering issues and challenges of the 21st Century
- Provide students with the technical background needed for the practice of civil engineering and to ensure their competence and literacy in both problem identification and problem solving, including design.
- Prepare students for leadership in the profession, including civil engineering practice, societal activities, research, licensing, and ethics.
- Provide students with a broad educational base, including a foundation in math, science, and engineering and exposure to the humanities and social sciences that prepares them for life-long learning
- Prepare students to thrive in the modern workplace and the public forums of civil engineering practice through the development of leadership, teamwork, and communication skills

After completing the core engineering sequence, a student enters this curriculum and follows a baccalaureate program leading to the B.S. degree or a professional program leading to the M.Eng. degree as well as the B.S.

Undergraduate concentrations include construction, environmental, geotechnical, structural, and transportation engineering. Following the sample four-year schedule is the recommended collection of courses for each of these concentrations.

Subject to other requirements, students may use core engineering electives to accelerate their entrance into the program. Students also may take courses in related fields. Courses bearing the following codes are suggested for particular consideration in consultation with the student's adviser: ARCH, ECSE, MANE, ENVE, MATH, CSCI, EARTH, and DSES.

The following represents a typical four-year civil engineering program. Students who are convinced that they want to become civil engineers are urged to follow this plan of study in lieu of the general core engineering program presented earlier. Required or strongly recommended core engineering electives are shown for optimum scheduling.

**First Year****Fall**

ENGR-1100	Intro. to Engineering Analysis.....4
ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....1
MATH-1010	Calculus I.....4
CHEM-1300	Chemical Principals for Engineers.....4
	Hum. or Soc. Sci. Elective .....4

**Credit hours****Spring**

ENGR-1300	Engineering Processes <sup>1</sup> .....1
PHYS-1100	Physics I..... 4
MATH-1020	Calculus II .....4
	Science Elective <sup>2</sup> ..... 4
	Hum. or Soc. Sci. Elective .....4

**Credit hours****Second Year****Fall**

ENGR-2050	Intro. to Engineering Design .....4
MATH-2400	Intro. to Differential Equations .....4
PHYS-1200	Physics II.....4
	Hum. or Soc. Sci. Elective .....4

**Credit hours****Spring**

ENGR-2090	Engineering Dynamics .....4
ENGR-2530	Strength of Materials .....4
	Multidisciplinary Elective I <sup>3</sup> .....4
	Hum. or Soc. Sci. Elective .....4
CSCI-1190	Beginning C Programming for Engineers <sup>4</sup> .....1

**Credit hours****Third Year****Fall**

CIVL-2030	Intro. to Transportation Eng.....4
CIVL-2630	Intro. to Geotechnical Eng .....4
CIVL-2670	Intro. to Structural Eng.....4
ENGR-2600	Modeling and Analysis of Uncertainty.....3

**Credit hours****Spring**

	Multidisciplinary Elective II <sup>3</sup> .....4
	CE Design Elective <sup>5</sup> .....3
	Professional Development II <sup>6</sup> .....2
	Math and Science Elective .....3-4
	Free Elective .....4

**Credit hours****Fourth Year****Fall**

ENVE-2110	Intro. to Environ. Eng. ....4
CIVL-4120	CE Instrumentation and Sensors .....4
	CE Design Elective <sup>5</sup> .....3
	Free Elective .....4

**Credit hours****Spring**

CIVL-4920	Civil Eng. Capstone Design.....3
ENGR-4010	Professional Development III <sup>7</sup> .....1
	CE Technical Elective <sup>5</sup> .....3
	Hum. or Soc. Sci. Elective .....4
	Free Elective .....4

**Credit hours**

<sup>1</sup> For these two courses, order does not matter. ENGR-1300 may be replaced with CIVL-2961.

<sup>2</sup> Choose either ENGR-1600 or CSCI-1100.

<sup>3</sup> For Multidisciplinary Elective I, choose either ENGR-2250 or ENGR-4750. For Multidisciplinary Elective II, choose either ENGR-2350 or ENGR-4300.

<sup>4</sup> Can be satisfied with Computer Science I.

<sup>5</sup> Text below lists the allowable courses.

<sup>6</sup> This course will be fulfilled from a list published at the start of each semester.

<sup>7</sup> Can be taken either semester of the senior year.

A minimum of 128 credit hours is required for this curriculum. Nonengineering courses graded satisfactory/unsatisfactory are not included within this 128-credit-hour requirement. The Pass/No Credit option can be used only for free electives with something other than a CIVL or ENVE code and the humanities and social sciences electives. All other courses used to satisfy the degree requirements must be taken on a graded basis.

### Civil Engineering Design Electives and Concentrations

Six credit hours of civil engineering design electives are required. These must be selected from the following list. Any pair of courses can be selected providing that prerequisites are met, but students most often select a combination focused on a specific area of concentration. The terms in which courses are offered are listed in parentheses.

#### Construction Engineering

CIVL-4070	Steel Design (Fall)
CIVL-4080	Concrete Design (Spring)
CIVL-4010	Foundation Engineering (Fall)
CIVL-4150	Experimental Soil Mechanics (Spring)

#### Structural Engineering

CIVL-4070	Steel Design (Fall)
CIVL-4080	Concrete Design (Spring)
CIVL-4960	Bridge Design (Spring) <sup>1</sup>

#### Environmental Engineering

ENVE-4200	Solid and Hazardous Waste Engineering
ENVE-4350	Biological Processes in Environmental Engineering

ENVE-4310	Applied Hydrology and Hydraulics
ENVE-4340	Physicochemical Processes in Environmental Engineering

#### Geotechnical Engineering

CIVL-4010	Foundation Engineering (Fall)
CIVL-4140	Geoenvironmental Engineering (Fall)
CIVL-4150	Experimental Soil Mechanics (Spring)

#### Transportation Engineering

CIVL-4620	Mass Transit Systems (Spring)
CIVL-4640	Transportation Facility Design and Planning (Spring)
CIVL-4660	Traffic Engineering (Fall)
CIVL-4670	Highway Engineering (Spring)

### Civil Engineering Technical Elective

Any of the design electives listed above can be taken as a CE technical elective, provided the necessary prerequisites are met. The following other civil engineering courses can also be selected:

CIVL-2040	Professional Practice	CIVL-4270	Construction Management
CIVL-2130	Surveying	CIVL-4440	Structural Analysis
CIVL-4240	Intro. to Finite Elements	CIVL-4580	Infrastructure Engineering

With adviser approval, courses from related disciplines can also be taken. These include architecture, environmental engineering, mechanical engineering, chemical engineering, industrial engineering, and operations research. Graduate level courses (6000-level) are allowable under certain circumstances. A representative list of such courses is as follows:

ARCH-4510	Construction Industry Seminar	ENVE-4200	Solid and Hazardous Waste Engineering
ARCH-4530	Systems Building Seminar	ENVE-4310	Applied Hydrology and Hydraulics
ARCH-4550	Building Economics	MATH-4800	Numerical Computing
ARCH-4750	Advanced Environmental Systems	ERTH-2120	Structural Geology
ENGR-4750	Engineering Economics and Project Management	ERTH-2330	Earth Materials
ENVE-4110	Aqueous Geochemistry	ERTH-4200	Surficial Geology
		ERTH-4710	Ground Water Hydrology

<sup>1</sup> Special topics course.

**Humanities or Social Sciences Electives**

In this area, the electives are based on the Institute and School of Engineering requirements. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

**Environmental Engineering Curriculum**

**Objectives of the Undergraduate Curriculum**

While certain objectives of an undergraduate education in engineering are common to all programs, there are subtle but important differences depending upon the student’s chosen field. In this regard, the Civil and Environmental Engineering Department’s baccalaureate program in Environmental Engineering will:

- Prepare students to be involved global citizens with a broad appreciation of the key environmental issues and challenges of the 21st Century
- Provide students with a broad educational base, including a foundation in math, science, and engineering and exposure to the humanities and social sciences that will prepare them for life-long learning
- Provide students with the technical background needed for the practice of environmental engineering and to insure their competence and literacy in both problem identification and solving, including design.
- Prepare students for professional engineering practice, including professional licensing, with awareness of the importance of personal and professional ethics
- Prepare students to thrive in the modern workplace and the public forums of environmental engineering practice through the development of leadership, teamwork, and communication skills

The Rensselaer bachelor’s program in environmental engineering builds upon a broad base of studies in chemistry, life sciences, and engineering sciences culminating in a uniquely structured course sequence. This sequence of courses, as shown below, is designed around the unit operations and transport processes concepts, together with integrated laboratory theory courses. It culminates in senior design courses. This structure presents a unified educational experience in environmental engineering. A minimum of 128 credit hours is required for this curriculum.

**First Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
ENGR-1100	Intro. to Engineering Analysis .....	4	PHYS-1100	Physics I .....	4
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
CHEM-1300	Chemistry Principles for Engineers....	4	ENGR-1600	Material Science for Engineers.....	4
ENGR-1200	Engineering Graphics and CAD <sup>1</sup> .....	1	ENGR-1300	Engineering Processes or	
	Hum. or Soc. Sci. Elective .....	4	ENGR-1310	Intro. to Eng. Electronics <sup>1</sup> .....	1
				Hum. or Soc. Sci. Elective .....	4

<sup>1</sup> May be taken in any order in the first two semesters. ENGR-1300 or ENGR-1310 may be replaced with CIVL-2961, Introduction to Civil and Environmental Engineering

**Second Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
PHYS-1200	Physics II .....	4	ENGR-2600	Modeling and Analysis of Uncertainty .....	3
MATH-2400	Intro. to Differential Equations .....	4	ENGR-2050	Intro. to Engineering Design <sup>2</sup> .....	4
ENVE-2110	Intro. Environmental Eng. ....	4		Hum. or Soc. Sci. Elective .....	4
CHEM-2270	Intro. to Organic Chemistry .....	3		Free Elective I .....	4
			CSCI-1190	Beginning C Programming for Engineers .....	1

**Third Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
CHME-4010	Fluid Mech. and Heat Transfer .....	4	ENVE-4310	Applied Hydrology and Hydraulics ..	3
ENVE-4330	Atmospheric Pollution .....	3	ENVE-4320	Technical Elective I <sup>3</sup> .....	3
	Free Elective II .....	4	ENVE-4320	Environmental Chemodynamics .....	3
	Hum. or Soc. Sci. Elective .....	4	ERTH-4180	Environmental Geology .....	4
	Professional Development II <sup>1</sup> .....	2	CHME-4030	Chem. Process Dyn. and Control .....	4

**Fourth Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
ENVE-4350	Biol. Proc. in Env. Eng. ....	4	ENVE-4340	Physicochem. Proc. in Env. Eng. ....	3
ENVE-4150	Environmental Eng. Lab I .....	2	ENVE-4160	Environmental Eng. Lab II .....	2
	Multidisciplinary Eng. Elec. I <sup>4</sup> .....	4		Technical Elective II <sup>3</sup> .....	3
	Hum. or Soc. Sci. Elective .....	4	ENVE-4180	Env. Proc. Design II .....	2
ENVE-4170	Env. Proc. Design I .....	1		Free Elective III .....	4
ENGR-4010	Professional Development III <sup>5</sup> .....	1			

**Minor Programs**

The department offers minors in both civil and environmental engineering.

**Civil Engineering**

Students not majoring in civil engineering may receive a minor in this field by completing 15 credit hours selected from the following list (subject to consultation with a department program adviser):

CIVL-2030	Intro. to Transportation Engineering	CIVL-4150	Experimental Soil Mechanics
CIVL-2630	Intro. to Geotechnical Engineering	CIVL-4070	Steel Design
CIVL-2670	Intro. to Structural Engineering	CIVL-4080	Concrete Design
ENVE-2110	Intro. to Environmental Engineering	CIVL-4660	Traffic Engineering
CIVL-4010	Foundation Engineering	CIVL-4670	Highway Engineering

<sup>1</sup> May be taken in any order in the first two semesters.

<sup>2</sup> Special section for environmental engineering students.

<sup>3</sup> Elective must be an engineering course with design content (e.g., ENVE-4200, ENVE-4240, ENVE-4210, ENVE-4110). Courses are selected in consultation with the program adviser. With adviser approval, courses from other disciplines may also be taken. These include Civil Engineering, Chemical Engineering, Earth and Environmental Sciences (for example, CIVL-2630, CIVL-4150, ERTH-4710 and others)

<sup>4</sup> Multidisciplinary engineering, elective: Must be an engineering course, chosen in consultation with the adviser (e.g., ENGR-4750, ENGR-4760, CIVL-2030, CIVL-2630, DSES-4260, ENGR-2530, ENGR-2830).

<sup>5</sup> This course will be fulfilled from a published list at the start of each semester and can be taken either semester.

Students pursuing this minor must satisfy the prerequisites and/or corequisites for these courses, which may involve other course work. Courses in mechanics and structures taught by the School of Architecture may be substituted for certain core engineering, mathematics, and mechanics/materials courses (with instructor approval).

### Environmental Engineering

Students not majoring in environmental engineering may receive a minor in this discipline by completing 15–16 credit hours of study beyond the Introduction to Environmental Engineering course. Typically these courses are chosen in consultation with the environmental engineering program adviser but may include:

ENVE-4260	Biological Processes in Environmental Engineering	<i>And one or more of:</i>	ENVE-4200	Solid and Hazardous Waste
ENVE-4340	Physicochemical Process in Environmental Engineering		ENVE-4330	Atmospheric Pollution
ENVE-4310	Applied Hydrology and Hydraulics		ENVE-4320	Environmental Chemodynamics

### Professional Program

This program is intended primarily as a preparation for professional practice. After core engineering study, qualified undergraduates may enter this program, which leads to the B.S. and the M.Eng. degrees. Students follow a coherent program integrating advanced undergraduate and graduate study. An additional 30 credit hours are required beyond the B.S. degree.

## Graduate Programs

Graduate programs leading to the M.Eng., M.S., D.Eng., and Ph.D. are available in both curricula. The selection of a graduate program and degree is based on student interest, area of graduate concentration, and satisfaction of prerequisites as indicated below.

### Master's Programs

#### Master of Science

This research degree is open to students with undergraduate degrees in engineering or the physical or natural sciences. In addition to the satisfactory completion of an approved set of advanced courses, candidates for this degree must complete a six-credit thesis.

In the civil engineering discipline, this thesis must provide documentation of an independent research-related effort and be approved by the student's faculty adviser. Listed below are recommended core courses in each of the five civil engineering areas of concentration and in Environmental Engineering. M.S. candidates typically take all the courses listed below in their chosen area of concentration.

#### Computational Mechanics

CIVL-6170	Mechanics of Solids
CIVL-6660	Fundamentals of Finite Elements
CIVL-6670	Nonlinear Finite Element Methods
CIVL-6680	Finite Element Programming

CIVL-6450	Structural Dynamics
CIVL-6540	Dynamics of Soil and Soil Foundations Systems

#### Structural/Earthquake Engineering

CIVL-6510	Advanced Soil Mechanics	CIVL-4240	Introduction to Finite Elements
CIVL-6520	Advanced Foundations of Earth Structures	CIVL-6200	Plates and Shells
CIVL-6550	Advanced Geoenvironmental Engineering	CIVL-6210	Structural Stability
		CIVL-6310	Advanced Concrete Structures
		CIVL-6320	Advanced Steel Design
		CIVL-6450	Structural Dynamics
		CIVL-6540	Dynamics of Soil and Soil Foundation Systems

**Infrastructure Engineering**

CIVL-4580	Infrastructure Engineering
CIVL-4570	Analytical Methods in Infrastructure Engineering
CIVL-4670	Highway Engineering or equivalent
CIVL-6280	Infrastructure Asset Management
ENGR-4760	Engineering Economics or equivalent
DSES-6020	Design of Experiments or equivalent
DSES-6090	Decision Analysis or equivalent

**Transportation Engineering**

CIVL-6230	Transportation Economics
CIVL-6250	Transportation Systems Planning
CIVL-6260	Transportation Algorithms
CIVL-6270	Traffic Control Systems

**Environmental Engineering**

ENVE-4350	Biological Processes in Env. Eng.
ENVE-4340	Physicochemical Processes in Env. Eng.
ENVE-4110	Aqueous Geochemistry

M.S. candidates in the environmental engineering discipline must also provide documentation of an independent research-related effort. In addition to approval of this written work, they are also required to give an oral presentation of the thesis work.

**Master of Engineering**

This is a 30-credit structured program of advanced professional study aimed at preparing students for professional practice. Except for computational mechanics, candidates for this degree in the civil engineering discipline must have an accredited bachelor's degree in engineering. In environmental engineering, a B.S. in the physical or natural sciences is also acceptable. There is no project or thesis requirement, but students may elect to do one, at either the three- or six-credit level, in consultation with their advisers.

**Doctoral Programs**

Advanced study and research are conducted under the guidance of an adviser. Usually 45 to 60 course credits beyond the bachelor's degree are required in addition to the residence and thesis requirements. Each doctoral candidate must have at least 90 credits (course work plus thesis/project) beyond the bachelor's degree. Environmental candidates are required to submit a draft of a journal article prior to graduation.

**Doctor of Philosophy**

This is a research-oriented degree focused on the development of new knowledge in the student's chosen area of study. It includes the preparation of a dissertation that carefully documents the original contribution of the student's research. The dissertation can represent up to 30 credits of the student's approved plan of study. In addition to the examination processes required of all Rensselaer doctoral students, civil engineering and environmental engineering students working toward this degree must pass a qualifying examination during student's second semester if student has a M.S. degree counting as a degree requirement or at the end of the student's fourth semester if student does not have a M.S. degree counting as a degree requirement.

Environmental engineering students must also take a candidacy examination within two semesters after passing the preliminary examination. This is an oral examination based on a thesis proposal submitted by the student at least two weeks prior to the examination. The student's thesis committee will administer the candidacy examination.

**Doctor of Engineering**

This is a specialized program aimed at advanced engineering problem solving. The degree includes the preparation of a dissertation that poses a significant engineering problem and develops a solution. The dissertation for this degree can also represent up to 30 credits of the student's approved plan of study. The examination requirements for both disciplines are the same as those noted under the Doctor of Philosophy.

## Course Descriptions

Courses directly related to all Civil and Environmental Engineering curricula are described in the Course Description section of this catalog under the department codes CIVL and ENVE.

# Decision Sciences and Engineering Systems

**Chair:** James M. Tien

**Associate Chair and Director, Master's Programs:** Charles J. Malmborg

**Director, Doctoral Program:** Sunderesh Heragu

**Director, Undergraduate Program:** Thomas Willemain

**Department Home Page:** <http://www.rpi.edu/dept/dses/www/>

The formation of the Decision Sciences and Engineering Department in 1987 is a prime example of Rensselaer's ability to anticipate the changing needs of the engineering profession. The department was created to (1) prepare engineers to design, develop, and implement complex systems and (2) to conduct research that leads to better understanding of how information technology and quantitative analysis and modeling can support individuals, groups, and systems in problem solving and decision making. DSES achieves these objectives by extending and integrating knowledge from the disciplines of industrial engineering, information systems, operations research, mathematical statistics, computational intelligence, bioinformatics, and systems engineering.

The Department of Decision Sciences and Engineering Systems offers programs in industrial and management engineering, service and manufacturing systems engineering, and operations research and statistics. Curricula in management engineering and/or industrial engineering have been offered since 1933. The interdisciplinary graduate program in operations research and statistics (OR&S) at Rensselaer was established in response to the rapid increase in the use of mathematical models for characterizing systems, understanding operations, and making decisions. Both a master's and a doctoral program were initiated in 1967. However, in 1988, the department replaced the OR&S Ph.D. with a unique Ph.D. degree in Decision Sciences and Engineering Systems, reflecting the focus of the new department. The program in service and Manufacturing Systems Engineering was inaugurated in the fall of 1992. This program is designed to emphasize modeling, statistical, computer, and management skills as they relate to service operations and the process of manufacturing. A common theme throughout these programs is the use of mathematical, statistical, and computational/simulation models to better understand engineering, managerial, operational, and physical processes.

## Research and Innovation Initiatives

### Manufacturing Systems

Faculty have developed methodologies and procedures for infrastructure and operating systems (e.g., production planning and control, scheduling, and dispatching in flexible manufacturing systems), simulation of production facilities, manufacturing logistics, materials handling engineering, manufacturing facility design, information integration for design and manufacturing, control systems and agile manufacturing concepts for the electronics industry, and methodologies to integrate statistical quality control with computer graphics.

### **Service Systems**

This area concentrates on the application of traditional and evolving industrial and systems engineering methodologies to the design and operation of service systems in both industry and the public sector. Areas of interest include simulation modeling and analysis, distribution and logistics, facilities design, work design, quality assurance, intelligent transportation systems, and engineering economic analysis. Also included is research in the deployment, allocation, and operation of urban service systems using computationally-intensive, real-time decision support approaches.

### **Information Systems**

Information and decision support systems have been developed and extensively used for disaster preparedness and management of disasters (e.g., searches for ships lost at sea, earthquakes) and manufacturing enterprises (e.g., manufacturing-driven design and scalable adaptive integration of databases over wide area networks). New theory and methodologies for Internet-based information integration, e-commerce, data mining, and knowledge discovery are being developed. Decision support systems are being developed using a variety of knowledge engineering and computational intelligence tools. Also under development are methods, models, and technologies to aid in the planning and design of distributed information systems, information visualization, and user interfaces.

### **Mathematical Programming**

Research topics include linear, nonlinear, integer, large-scale, multiple-objective, combinatorial, geometric, and stochastic programming. Of particular interest is research on the development and analysis of algorithms, computation, and the integration of uncertainty in optimization.

### **Statistics and Applied Probability**

Research is conducted in the areas of real-time data fusion and analysis, data mining, knowledge discovery, and design of experiments—including optimality, efficiency, and robustness; nonlinear and robust estimation; statistical computing; probability; stochastic processes; queuing theory; reliability; quality control; and forecasting.

Facilitating these research programs are three research centers based directly within the Decision Sciences and Engineering Systems Department. Every department faculty member is involved in one or more of these research centers. In addition, several other faculty in the School of the Engineering, as well as in the other four schools, are also participating in activities conducted in the centers described below:

#### **Electronics Agile Manufacturing Research Institute (EAMRI)**

The EAMRI grew out of a federally funded, five-year project focused on agile manufacturing information technologies as a strategy to help the electronics manufacturing industry achieve its goals. Agile manufacturing concepts employ network-based information for supply chain-oriented technologies and organizations, as well as improved communications to help solve design and manufacturing problems. The EAMRI provides a national focus for developing and sharing methods to enable the U.S. electronics industry to adopt agile manufacturing. Experts in electronics design and manufacturing, the EAMRI faculty possess engineering, computer science, and management backgrounds. The EAMRI's initial information technology, known as the Virtual Design Environment, has recently received a patent from the U.S. Patent Office.

#### **Center for Services Research and Education (CSRE)**

The goal of the CSRE is to enhance our understanding of the service sector and its function, and to educate students and managers seeking careers in the services industry, which accounts for more than three-quarters of the U.S. gross national product. CSRE faculty were one of the first groups to highlight

the duality between services and manufacturing; many manufacturing methods are applicable to service systems and can be employed to enhance productivity and competitiveness. The CSRE takes a holistic approach to the multifaceted service sector and brings together experts from engineering, marketing, psychology, economics, and management policy and organization, among others. Experts examine the common elements that characterize all aspects of the service sector and develop generic principles that apply across the wide spectrum of services, including the advancement of a focus in service systems engineering.

### **Rensselaer Statistical Consulting Center (RSCC)**

The RSCC provides statistical planning and analysis services to Rensselaer researchers who require them. It also consults with companies and government agencies that require advice on state-of-the-art statistical and probabilistic methods and their applications. In addition, it allows graduate students to apply, in a supervised manner, established and new statistical and probabilistic approaches to real-world problems, and offers general and organization-specific short-term training programs and state-of-the-art courses in statistical methodologies and practices. The Center's faculty represent a range of statistical expertise, and they have extensive research and consulting experience. These faculty members, together with talented graduate students, provide advice and guidance on the appropriate use of statistical and probabilistic methods, on a consulting or short course basis.

## **Faculty\***

### **Professors**

- Berg, D.**—NAE, Ph.D. (Yale University) Institute Professor of Science and Technology (joint in Lally School of Management and Information Technology); management of technological organizations, innovation, policy, robotics, policy issues of research and development in the service sector.
- Ecker, J.G.**—(Mathematical Sciences) Ph.D. (University of Michigan); mathematical programming, multiobjective programming, geometric programming, mathematical programming applications, ellipsoid algorithms.
- Heragu, S.S.**—Ph.D. (University of Manitoba); artificial intelligence, cellular manufacturing, facilities design, intelligent manufacturing systems, materials handling, next-generation factory layout design, production and operations management, operations research, scheduling, storage and warehousing.
- Hsu, C.**—Ph.D. (Ohio State University); electronic commerce, metadata and information systems, enterprise integration and modeling, internet enterprises planning, computerized manufacturing, information visualization, economic evaluation of cyberspace-augmented enterprises.
- Hughes, G.**—(Economics) Ph.D. (Princeton University); global economics, economics of information technology; Clinical Professor.
- List, G.F.**—(Civil Engineering) P.E., Ph.D. (University of Pennsylvania); real-time control of transportation network operations; multiobjective routing, scheduling, and fleet sizing; operations planning; hazardous materials logistics.
- Malmberg, C.J.**—Ph.D. (Georgia Institute of Technology); modeling and analysis of problems in facility design, materials handling, material flow, storage systems, simulation-based optimization methods, manufacturing systems, decision analysis.
- Mitchell, J.E.**—(Mathematical Sciences) Ph.D. (Cornell University); mathematical programming integer programming, interior point methods, column generation methods, financial optimization, stochastic programming.
- Pang, J.S.**—(Mathematical Sciences) Ph.D. (Stanford University); Mathematics of Finance and Mathematical Statistics

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

**Raghavachari, M.**—Ph.D. (University of California at Berkeley); statistical inference, quality control, multivariate methods, scheduling problems.

**Tien, J.M.**—NAE, Ph.D. (Massachusetts Institute of Technology) Yamada Corporation Professor (joint in Electrical, Computer, and Systems Engineering; IT); systems modeling, queuing theory, public policy and decision analysis, computer performance evaluation, and information and decision support systems, expert systems, computational cybernetics.

**Wallace, W.A.**—Ph.D. (Rensselaer Polytechnic Institute) (joint in Civil Engineering; Cognitive Sciences; IT); decision support systems, environmental management modeling process, disaster management.

**Willemain, T.R.**—Ph.D. (Massachusetts Institute of Technology); probabilistic modeling, data analysis, forecasting.

### Associate Professors

**Embrechts, M.J.**—Ph.D. (Virginia Polytechnic Institute); application of neural networks and fuzzy logic for manufacturing and process control; image recognition and classification with the aid of neural networks; smart experiments; neural networks for trading and finance; neural networks, fractals, chaos, and wavelets for time-series analysis; data mining and computational intelligence.

**Foley, W.J.**—P.E., Ph.D. (Rensselaer Polytechnic Institute); engineering design, computer simulation modeling, health applications of operations research, health case policy analysis; Clinical Associate Professor.

**Holguin-Veras, J.**—(Civil and Environmental); Ph.D. (University of Texas/Austin); transportation modeling and transportation economics, information technology, information systems, optimization techniques.

**Sullo, P.**—Ph.D. (Florida State university); reliability, life testing, statistical quality control, quality management, biostatistics, industrial statistics.

### Assistant Professors

**Aboul-Seoud, M.**—Ph.D. (University of Louisville); reliability engineering, quality control, operations research; Clinical Assistant Professor.

**Gupta, A.**—Ph.D. (Stanford University); behavioral aspects of optimization and application problems in finance, large-scale problems in decision making, simulation methods and tools for solving large-scale problems, simulation-based optimization.

**Krishnamurthy, A.**—Ph.D. (University of Wisconsin-Madison); queuing models and simulation based approaches for design and analysis of manufacturing systems, quick response manufacturing, queuing networks, analytical models in fabrication/assembly systems.

**Yang, Y.**—(Cognitive Science) Ph.D. (New York University); cognitive psychology, thinking, reasoning, decision-making, cognitive science.

### Adjunct Faculty

**Hahn, G.**—Ph.D. (Rensselaer Polytechnic Institute); applied statistics, operations research.

**Kupferschmid, M.**—P.E., Ph.D. (Rensselaer Polytechnic Institute); mathematical programming, algorithm performance evaluation, engineering applications.

**Lawrence, C.**—Ph.D. (Cornell University); statistical methods for bioinformatics, biometrics, Bayesian statistics, sequential analysis, statistical computing.

**Mars, C.M.**—B.S. (Rensselaer Polytechnic Institute); industrial safety and hygiene.

**Sandhu, D.**—Ph.D. (University of Toronto); stochastic models in operations research, complex queuing networks, applications to communication and manufacturing systems.

**Stephens, P.**—M.S. (Rensselaer Polytechnic Institute); Statistics and Operations Research

**Tucker, W.**—Ph.D. (Oklahoma State); applied statistics, operations research, quality control.

**Affiliated Professors**

- Desrochers, A.**—(Electrical, Computer, and Systems Engineering) Ph.D. (Purdue University); performance modeling of automated manufacturing systems application to Petri nets, transfer lines, manufacturing architectures, database and network transactions, distributed systems.
- Haddock, J.**—(Lally School of Management); Ph.D. (Purdue University); mathematical and simulation modeling, just-in-time manufacturing, lean management techniques, corporate paradigms.
- Kelly, L.J.**—(Rensselaer at Hartford) Ph.D. (University of Connecticut); statistics, operations management; Clinical Associate Professor.
- Norsworthy, J.R.**—(Lally School of Management and Technology) Ph.D. (University of Virginia); economics of productivity, productivity measurements, industrial economics.
- Paulson, A.S.**—(Lally School of Management and Technology) Ph.D. (Virginia Polytechnic Institute); risk management, financial models, multivariate statistics, time series and forecasting, survival data analysis.

**Affiliated Associate Professors**

- Bennett, K.**—(Mathematical Sciences) Ph.D. (University of Wisconsin); mathematical programming, operations research, artificial intelligence.
- Franklin, W.R.**—(Electrical, Computer, and Systems Engineering) Ph.D. (Harvard University); computational geometry, graphics, CAD, cartography, parallel algorithms, large databases, expert system verification.
- Goldenberg, D.H.**—(Lally School of Management and Technology) Ph.D. (University of Florida); derivatives markets, stochastic modeling of prices, options in corporate finance.
- Gutierrez-Miravete, E.**—(Rensselaer at Hartford) Ph.D. (Massachusetts Institute of Technology); materials processing, transport phenomena, clean technologies, advanced mathematics for applications, numerical computing, mathematical modeling, computer simulation.
- Maleyeff, J.**—(Rensselaer at Hartford) Ph.D. (University of Massachusetts); statistical quality assurance in manufacturing, administration and health care; computer simulation of operating systems; development of effective teaching methodologies.
- Messac, A.**—(Mechanical, Aerospace and Nuclear Engineering); Ph.D. (Massachusetts Institute of Technology); multiattribute design optimization, design and manufacturing, concurrent engineering.

**Affiliated Assistant Professor**

- Arnheiter, E.D.**—(Rensselaer at Hartford) Ph.D. (University of Massachusetts); Monte Carlo simulation and probabilistic models in quality, modular consortiums, and automotive production models.
- Ravichandran, T.**—(Lally School of Management and Technology) Ph.D. (Southern Illinois University, Carbondale); management information systems.
- Zaki, M.J.**—(Computer Sciences) Ph.D. (University of Rochester); design of efficient, scalable, and parallel algorithms for various data mining techniques.

**Research Professors**

- Grabowski, M.**—Ph.D. (Rensselaer Polytechnic Institute); management information systems, knowledge-based systems, human and organizational error in large-scale systems, impact of information technology on systems and organizations.
- Graves, R.J.**—Ph.D. (State University of New York at Buffalo); manufacturing systems modeling and analysis, facilities planning and material handling system design, scheduling systems, concurrent engineering and design for manufacture, continuous flow manufacturing systems design, distributed manufacturing concepts, information infrastructure.

**Emeritus Faculty**

**Graves, R.J.**—Ph.D. (State University of New York at Buffalo); manufacturing systems modeling and analysis, facilities planning and material handling system design, scheduling systems, concurrent engineering and design for manufacture, continuous flow manufacturing systems design, distributed manufacturing concepts, information infrastructure.

**Wilkinson, J.**—Ph.D. (University of North Carolina); regression modeling, statistical analysis

## Undergraduate Programs

### Objectives of the Undergraduate Curriculum

While certain objectives of an undergraduate education in engineering are common to all programs, there are subtle but important differences for ensuring that all graduates have specialized technical knowledge in their chose field. In this regard, the Department of Decision Sciences and Engineering Systems baccalaureate program educates students in the fundamental theories, principles, methodologies and practices of Industrial and Management Engineering while seeking to develop in its graduates:

- The ability to apply a total integrated systems perspective to the practice of industrial and management engineering.
- The ability to apply knowledge of manufacturing and service systems to the practice of industrial and management engineering.
- The ability to apply in-depth knowledge of computing to the practice of industrial and management engineering.
- The ability to manage people and systems.
- The ability to design innovative products, services, facilities, equipment, processes and systems.
- The ability to identify, model, analyze, and solve challenging real-life problems.
- A solid foundation in math and science.
- Strong communication skills with emphasis on technical writing and interpersonal communication.
- The ability to perform effectively on diverse teams, both as leader and contributor.
- Informed citizens broadly educated in the humanities and social sciences.
- Preparation to practice engineering in a socially responsible and ethical manner.
- Motivation and preparation for continued growth and learning.

## Baccalaureate Programs

The Department of Decision Sciences and Engineering offers a curriculum in Industrial and Management Engineering (IME). The first two years of this curriculum provide a strong foundation in basic science, engineering science, mathematics, and the humanities and social sciences. These two years are oriented toward the quantitative (mathematical) approach. Computer-based technology, including simulation, modeling, and systems design, is emphasized. In the last two years of the program, students concentrate on building expertise in statistics, operations research, manufacturing, and services systems engineering, and industrial engineering methods and models. Through the appropriate choice of electives, students can focus on their selected areas of interest. Design projects include problems in both manufacturing and service systems, including information and public systems. It is advisable to develop a plan of study leading to the desired degree and concentration by the beginning of the third year.

DSES recommends that students declare their intent to major in industrial and management engineering as early as possible in their academic career. Students are also urged to work closely with their assigned faculty advisers to ensure that all degree requirements are satisfied. This curriculum requires a minimum of 128 credit hours and completion of the course requirements shown in the typical four-year program presented below.

## Industrial and Management Engineering Undergraduate Degree

### Proposed November 2003

#### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Introduction to Engineering		ENGR-1200	Engineering Graphics & CAD	.....1
	Analysis	.....4	MATH-1020	Calculus II	.....4
ENGR-1300	Engineering Processes	.....1	PHYS-1100	Physics I	.....4
MATH-1010	Calculus I	.....4		Science Elective <sup>1</sup>	.....4
CHEM-1300	Chem. Principles for Engineers	.....4		Hum. or Soc. Sci. Elective	.....4
	Hum. or Soc. Sci. Elective	.....4			

#### Second Year

Fall		Credit hours	Spring		Credit hours
ENGR-2050	Introduction to Engineering		ENGR-2600	Modeling and Analysis of	
	Design	.....4		Uncertainty	.....3
MATH-2400	Intro. to Differential Equations	.....4	CSCI-1190	C Programming	.....1
PHYS-1200	Physics II	.....4	DSES-2210	Prod & Ops Mgt & Cost Acctg.	.....4
	Hum. or Soc. Sci. Elective	.....4		Multidisciplinary Engineering	
				Elective <sup>2</sup>	.....3-4
				Multidisciplinary Engineering	
				Elective <sup>2</sup>	.....3-4

#### Third Year

Fall		Credit hours	Spring		Credit hours
DSES-4140	Statistical Analysis	.....4	DSES-4620	Operations Research II	.....3
DSES-4610	Operations Research I	.....3	DSES-4230	Quality Control	.....3
	Management Elective <sup>6</sup>	.....4	ENGR-4760	Eng. Economics	.....3
	Hum. or Soc. Sci. Elective	.....4		Hum. or Soc. Sci. Elective	.....4
	Professional Development II <sup>3</sup>	.....2		Free Elective	.....3-4

**Fourth Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
DSES-4530	Information Systems .....	4	DSES-4270	IME Design <sup>5</sup> .....	3
DSES-49XX	Supply Chain Management .....	3	ENGR-4100	Professional Development III <sup>5</sup> .....	1
	Technical Elective <sup>4</sup> .....	3	DSES-49XX	Discrete Event Simulation .....	3
	Technical Elective <sup>4</sup> .....	3		Technical Elective <sup>4</sup> .....	3
	Free Elective .....	3-4		Free Elective .....	3-4

**Electives**

The free electives indicated above may be chosen from any academic discipline to broaden the student’s educational background and/or develop greater depth in a selected discipline.

**Humanities and Social Sciences Electives**

The electives in this area are based on the Institute and School of Engineering requirements. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

**Special Undergraduate Opportunities**

**Cooperative Education Program**

DSES encourages this option, which allows students to gain professional experience as part of the educational program. Additional information on co-op opportunities is included in the Educational Programs and Resources section of this catalog, as well as through the faculty adviser or the Career Development Center.

<sup>1</sup> Students may take any approved four-credit course in science, computer science, or mathematics.

<sup>2</sup> Students must select any two of the following approved multidisciplinary electives:

ENGR-1600 Materials Science for Engineers	ENGR-2530 Strength of Materials
ENGR-2090 Engineering Dynamics	ENGR-2710 General Manufacturing Processes
ENGR-2250 Thermal and Fluid Engineering I	ENGR-4050 Modeling and Control of Dynamic Systems
ENGR-2350 Embedded Control	ENGR-4300 Electronic Instrumentation

<sup>3</sup> This course can be fulfilled by taking a two-credit course from a list of courses published at the start of each semester.

<sup>4</sup> Students may select any three of the following courses to satisfy technical elective requirements:

DSES-4200 Design and Analysis of Work Systems	DSES-4260 Industrial Safety and Hygiene
DSES-4240 Engineering Project Management	DSES-4810 Computational Intelligence
DSES-4250 Facilities Design & Industrial Logistics	DSES-4280 Dec. Focused Systems Engineering

Certain graduate level DSES courses can also serve as technical electives for eligible undergraduates with permission of the instructor and the adviser.

<sup>5</sup> May be taken in either Fall or Spring semester.

<sup>6</sup> Students may select any one of the following courses to satisfy the management elective requirement:

MGMT-1100 Introduction to Management	MGMT-4520 Technological Entrepreneurship
MGMT-2320 Accounting for Decision Making	MGMT-4530 Starting Up a New Venture
MGMT-4430 Marketing Principles	MGMT-4850 Managing the High Perf. Org I
MGMT-4510 Invention, Innovation & Entrepreneur.	MGMT-4860 Managing the High Perf. Org II

## Graduate Programs

### Master's Programs

The Department of Decision Sciences and Engineering Systems offers two master's level degrees, both of which can be earned within each of three curricula. These curricula and their individual requirements are described below.

#### Industrial and Management Engineering (IME) Curricula

Students can work toward either the M.S. degree, which requires a project or thesis, or the nonthesis M.Eng. degree. These IME degrees are also available through distance learning. Contact the Office of Professional and Distance Education for course scheduling information.

In general, all applicants to the IME master's programs must take the Graduate Record Exam (GRE). This requirement is especially important for those requesting financial aid, due to the large number of aid requests. However, for students applying to the M.Eng. program, the GRE may sometimes be waived. In special situations, and with departmental approval, the GMAT may be substituted for the GRE.

All students seeking either of the IME master's degrees must have completed the following two courses in their undergraduate program at Rensselaer or have had the equivalent courses elsewhere:

Applied Operations Research (equivalent to DSES-6610 Systems Modeling and Decision Sciences)

Introduction to Applied Statistics (equivalent to DSES-6110)

Both IME master's degrees require a minimum of 30 credit hours.

In addition to the above prerequisite courses, a student's core course work must include:

DSES-6470	Global Strategic Management of Technological Innovation	DSES-6620	Discrete Event Simulation
DSES-6500	Information and Decision Technologies for Industrial and Service Systems	DSES-6xxx	Applied Statistics Elective (One graduate course from those listed under the Applied Probability and Statistics and Quality Control concentration.)
DSES-6600	Models for Production Control and Service Logistics		

For students seeking the M.S. degree, three to nine of the 30 credit hours must be in DSES-6990 (Master's Thesis) or DSES-6980 (Master's Project). The thesis or project credits can also count toward the nine-credit-hour (three-course) concentration that the program requires.

While the remainder of the program may be tailored to the student's interest, the plan of study must include a concentration area. The concentration is a set of three or more courses (or nine credit hours) that reflects a logical progression for developing a base of expertise in an area of study. Concentrations will usually, but not always, include at least one of the core courses listed above. Listed below are several concentration areas and the courses that are within each area.

<b>Applied Operations Research Concentration</b>			
DSES-4770	Mathematical Models of Operations Research	DSES-6760	Combinatorial Optimization and Integer Programming
DSES-4780	Computational Optimization	DSES-6770	Linear Programming
DSES-6050	Stochastic Processes	DSES-6780	Nonlinear Programming
DSES-6200	Models in Facilities Planning and Materials Handling	DSES-6820	Queuing Systems and Applications
DSES-6210	Theory of Production Scheduling	DSES-6830	Large-Scale Systems: Case Studies and Analyses
DSES-6630	Continuous Simulation and Financial Mathematics	DSES-6840	Modeling Large-Scale Systems
		DSES-6860	Evaluation Methods for Decision Making
		DSES-6890	Multiple Criteria Decision Making

### Applied Probability and Statistics and Quality Control Concentration

DSES-4750	Probability Theory and Applications
DSES-4760	Mathematical Statistics
DSES-6010	Applied Regression Analysis
DSES-6020	Design of Experiments
DSES-6030	Sampling Methods
DSES-6040	Nonparametric Methods
DSES-6050	Stochastic Processes
DSES-6060	Applied Multivariate Analysis
DSES-6070	Statistical Methods for Reliability Engineering
DSES-6090	Decision Analysis
DSES-6100	Time Series Analysis
DSES-6140	Exploratory Data Analysis
DSES-6150	Advanced Probability for Statistical Inference
DSES-6170	Management of Quality Processes and Reliability
DSES-6180	Introduction to Knowledge Discovery with Data Mining
DSES-6230	Quality Control and Reliability

### Information Systems Concentration

DSES-4810	Computational Intelligence
DSES-6220	Concurrent Engineering
DSES-6500	Information and Decision Technologies for Industrial and Service Systems
DSES-6520	Enterprise Database Systems
DSES-6530	Decision Support and Expert Systems
DSES-6550	Information Systems Analysis and Design
DSES-6560	Information Technology and Systems for Enterprise Engineering
DSES-6570	Information Technology and Systems for E-Business
DSES-6870	Introduction to Neural Networks

### Management of Technology Concentration

MGMT-6690	Supply Chain Mgmt. for E-Business
MGMT-6960	Knowledge Based Operations Management
MGMT-6240	Financial Trading and Investment
MGMT-6490	Competitive Advantage and Operations Strategy
DSES-6470	Global Strategic Management of Technological Innovation
DSES-6480	Service Operations Management
DSES-6830	Large-Scale Systems: Case Studies and Analyses
DSES-6860	Evaluation Methods for Decision Making

### Manufacturing Systems Concentration

DSES-4200	Design and Analysis of Work Systems
DSES-4250	Facilities Design and Industrial Logistics
DSES-6200	Models in Facilities Planning and Materials Handling
DSES-6210	Theory of Production Scheduling
DSES-6220	Concurrent Engineering
DSES-6230	Quality Control and Reliability
DSES-6560	Information Technology and Systems for Enterprise Engineering
DSES-6600	Models for Production Control and Service Logistics
DSES-6960	Management of Manufacturing Supply Chains

### Service Systems Concentration

DSES-6480	Service Operations Management and at least two courses from the list below:
MGMT-4370	Risk Management
DSES-6170	Management of Quality Processes and Reliability
DSES-6860	Evaluation Methods for Decision Making
DSES-6980	Master's Project in Service Systems

### Service and Manufacturing Systems Engineering Curricula

The Department of Decision Sciences and Engineering Systems offers the Master of Engineering and Master of Science degrees in Service and Manufacturing Systems Engineering. This program combines modeling, statistical, computer, design and management skills focused on the operations of service and manufacturing systems. The program core provides a skill base in operations engineering with a balance of applications in services and manufacturing. Course work concentrations allow specialization in Service Operations or Manufacturing Processes.

All applicants are encouraged to take the Graduate Record Exam (GRE). GRE completion is especially important for those requesting financial aid, due to the large number of aid requests. The GMAT may be substituted for the GRE for students applying to the Master of Engineering program.

All students seeking the Master of Engineering or Master of Science degree in Service and Manufacturing Systems Engineering must complete the following course in their undergraduate program while at Rensselaer or have had the equivalent course work elsewhere:

### **DSES-6110 Introduction to Applied Statistics**

The Master of Engineering and Master of Science degrees in service and manufacturing systems engineering are 30-credit-hour programs of study. The prerequisite course may be counted toward the 30 credit hour total if taken at Rensselaer and included in the Master's Plan of Study.

In addition to the above prerequisite courses, a student's core course work will include:

DSES-6570	Information Technology and Systems for E-Business	DSES-6820	Queuing Systems and Applications
DSES-6610	Systems Modeling and Decision Sciences	MGMT-6960	Knowledge Based Operations Management
DSES-6620	Discrete Event Simulation		

### **Concentrations**

Students must select the remaining 4 to 5 courses in the Plan of Study from either the Service Operations or Manufacturing Processes concentrations. These concentrations are summarized below:

#### **Service Operations Concentration**

DSES-6140	Exploratory Data Analysis	DSES-6860	Evaluation Methods for Decision Making
DSES-6180	Knowledge Discovery with Data Mining	DSES-6870	Introduction to Neural Networks
DSES-6470/MGMT-6610	Global Strategic Management of Technological Innovation	DSES-6990/6980	Master's Project in Service Systems
DSES-6480/MGMT-6480	Service Operations Management	MATH-4740	Mathematics of Finance
DSES-6630	Continuous Simulation and Financial Mathematics	MGMT-6240	Financial Trading and Investing
		MGMT-6690	Supply Chain Management for E-Business

**Manufacturing Processes Concentration**

DSES-6070	Statistical Methods for Reliability Engineering	DSES-6600	Models for Production Control & Service Logistics
DSES-6100	Time Series Analysis	DSES-6960	Management of Manufacturing Supply Chain
DSES-6170/MGMT-6470	Management of Quality Processes and Reliability	DSES-6990/6980	Master's Project in Manufacturing Systems
DSES-6200	Models for Materials Handling and Facility Design	MANE-6800	Manufacturing Systems Integration
DSES-6210	Theory of Production Scheduling	MGMT-6490	Competitive Advantage and Operations Strategy
DSES-6220	Concurrent Engineering		
DSES-6230	Quality Control and Reliability		

For students seeking the Master of Science degree, three to nine of the 30-credit-hour program must be taken under DSES-6990 (Master's Thesis in Service Systems or Master's Thesis in Manufacturing Systems) or DSES-6980 (Master's Project in Service Systems or Master's Project in Manufacturing Systems).

**Operations Research and Statistics Curricula**

In this curriculum, DSES offers M.S. and M.Eng. degree programs that combine course work in applied probability and statistics, optimization, modeling, and decision sciences in the scientific application of quantitative tools to support decision making. The scope of the programs includes the formulation, solution, and implementation of mathematical models of decision problems to measure, evaluate, and optimize system performance. Most students can complete either program in 30 credit hours. Any student planning to enroll in the DSES doctoral program should consult with the faculty adviser prior to making course selections.

The diversity of this curriculum's faculty enables these programs to encompass varied research topics. A student may work simultaneously on a master's degree in this program and on a degree in computer science, business administration, mathematics, computer and systems engineering, or another related area.

Most students participating in this curriculum hold a bachelor's or master's degree in engineering, mathematics, the physical sciences, business administration, or management. Students with training in other disciplines such as economics and the social sciences are also encouraged to apply if their quantitative backgrounds include the equivalent of at least three semesters of calculus and linear algebra.

All applicants are required to take the Graduate Record Examination (GRE) except under extenuating circumstances.

For the master's programs in operations research and statistics, no prerequisites are required. However, the following courses or their equivalents are required.

<b>Credit hours</b>				<b>Credit hours</b>		
DSES-4640	Operations Research I .....	4	or	DSES-6820	Queuing Systems & Applications ....	3
and						
DSES-4750	Probability Theory & Applications. ..	4	and	DSES-6620	Discrete-Event Simulation .....	3
and						
DSES-4760	Mathematical Statistics.....	4	and	DSES-6060	Applied Multivariate Analysis .....	3
and						
DSES-6050	Stochastic Processes.....	3	or	DSES-6140	Exploratory Data Analyses.....	3
or						
DSES-6150	Advanced Probability for Statistical Inference .....	3	and		Modeling Optimization Elective .....	3*

While the remainder of the program may be tailored to the student's interest, the Plan of Study must include a concentration area. The concentration is a set of three or more courses (or nine credit hours) that reflects a logical progression for developing a base of expertise in an area of study. Concentrations will usually, but not always, include at least one of the core courses listed above. Listed below are several concentration areas and the courses that are within each area.

#### **Quality and Reliability Concentration**

DSES-6020	Design of Experiments
DSES-6050	Stochastic Processes
DSES-6070	Statistical Methods for Reliability Engineering
DSES-6150	Advanced Probability for Statistical Inference
DSES-6170	Management of Quality Processes and Reliability
DSES-6230	Quality Control and Reliability

#### **Forecasting Concentration**

ECON-6570	Econometrics
DSES-6010	Applied Regression Analysis
DSES-6060	Applied Multivariate Analysis
DSES-6100	Time Series Analysis
DSES-6130	Statistical Computing
DSES-6140	Exploratory Data Analysis
DSES-6150	Advanced Probability for Statistical Inference
DSES-6870	Introduction to Neural Networks

#### **Decision Analysis Concentration**

DSES-4750	Probability Theory and Applications
DSES-6090	Decision Analysis
DSES-6500	Information and Decision Technologies for Industrial and Service Systems
DSES-6530	Decision Support and Expert Systems

DSES-6830	Large-Scale Systems: Case Studies and Analyses
DSES-6860	Evaluation Methods for Decision Making
DSES-6890	Multiple Criteria Decision Making

#### **Modeling/Optimization Concentration**

DSES-4770	Mathematical Models of Operations Research
DSES-4780	Computational Optimization
DSES-6200	Models in Facilities Planning and Materials Handling
DSES-6210	Theory of Production Scheduling
DSES-6760	Combinatorial Optimization and Integer Programming
DSES-6770	Linear Programming
DSES-6780	Nonlinear Programming
DSES-6840	Modeling Large-Scale Systems
DSES-6870	Introduction to Neural Networks

#### **Simulation Concentration**

DSES-6630	Continuous Simulation and Financial Mathematics
	at least two of the following courses:
DSES-6020	Design of Experiments
DSES-6050	Stochastic Processes
DSES-6100	Time Series Analysis
DSES-6150	Advanced Probability for Statistical Inference

\* Any course listed under the Modeling/Optimization Concentration except DSES-4770.

DSES-6820 Queuing Systems and Applications  
 DSES-6870 Introduction to Neural Networks

### Data Mining Concentration

DSES-4810 Computational Intelligence  
 DSES-6010 Applied Regression Analysis  
 DSES-6020 Design of Experiments  
 DSES-6030 Sampling Methods  
 DSES-6040 Nonparametric Methods  
 DSES-6060 Applied Multivariate Analysis  
 DSES-6100 Time Series Analysis  
 DSES-6130 Statistical Computing  
 DSES-6140 Exploratory Data Analysis  
 DSES-6180 Introduction to Knowledge Discovery  
 with Data Mining  
 DSES-6870 Introduction to Neural Networks

### Information Systems Concentration

DSES-4810 Computational Intelligence  
 DSES-6500 Information and Decision  
 Technologies for Industrial and  
 Service Systems  
 DSES-6520 Enterprise Database Systems

DSES-6530 Decision Support and Expert Systems  
 DSES-6560 Information Technology and Systems  
 for Enterprise Engineering  
 DSES-6620 Discrete-Event Simulation  
 DSES-6870 Introduction to Neural Networks

### Financial Engineering Concentration

MATH-4200 Mathematical Analysis I  
 MGMT-4370 Risk Management  
 MATH-4740 Mathematics of Finance  
 DSES-6630 Continuous Simulation and  
 Financial Mathematics  
 MGMT-6240 Financial Trading and Investment  
 DSES-6010 Applied Regression Analysis  
 DSES-6060 Applied Multivariate Analysis  
 DSES-6100 Time Series Analysis  
 DSES-6130 Statistical Computing

### Marketing Research Concentration

DSES-6010 Applied Regression Analysis  
 DSES-6060 Applied Multivariate Analysis  
 DSES-6130 Statistical Computing  
 DSES-6520 Enterprise Database Systems

## Doctoral Programs

Students working toward the Ph.D. in DSES may choose to major in industrial engineering, information systems, manufacturing and service systems engineering, operations research, or statistics. Advanced research and a dissertation in the chosen field are required in the doctoral program. In addition, Ph.D. students must complete the following:

- Institution requirements established by the Office of Graduate Education.
- Seminar in DSES research: Doctoral students must complete DSES-6900 during the fall semester of the first academic year of residency. This course is intended to introduce the student to the research environment at Rensselaer and to provide background on the process of doctoral research in DSES. Another intent of the course is to develop the student's communication skills.
- Doctoral qualifying examination: Each student must take an oral examination covering the core areas of DSES. The basis for this examination includes DSES-4530, DSES-4750, DSES-4760, DSES-4770, and DSES-6500 or their equivalents. A more detailed description of this and other required examinations is available from the DSES doctoral program director.
- Doctoral area and advanced seminar requirement: Doctoral students must register for and complete course work in a selected major area. See the DSES doctoral program director for detailed documentation of DSES doctoral area requirements.
- Doctoral candidacy examination: Each student must take an oral candidacy examination after passing the DSES area requirement but before completing 75 credit hours of graduate work. This examination tests the candidate's background for the proposed research, appropriateness of the thesis research, and the ability of the candidate to successfully complete the research. The thesis research proposal must contain at least one result that meets journal publishing standards.

- **Doctoral dissertation and defense:** Each student must write a doctoral thesis and give a formal oral public defense.

Apart from the seminar in DSES research, doctoral area course requirements, and equivalent course material for the doctoral qualifying examination, there are no additional course requirements for the doctoral degree. However, the student is expected to develop in-depth knowledge in his/her dissertation area through appropriate course work, as well as supervised research. A plan of study is required, which must be approved by the thesis adviser and the DSES doctoral program director. Representative programs of study are available from the DSES doctoral program director.

## Course Descriptions

Courses directly related to all Decision Sciences and Engineering Systems curricula are described in the Course Description section of this catalog under the department code DSES.

# Electrical, Computer, and Systems Engineering

**Chair:** Kenneth A. Connor

**Director of Master's Programs:** Yannick L. LeCoz

**Director of Doctoral Programs:** Alan A. Desrochers

**Department Home Page:** <http://www.ecse.rpi.edu/>

Electrical, computer, and systems engineers have long been at the forefront of new discoveries and their integration into advanced design and engineering methodologies. Inventions in areas such as integrated electronics and optical devices stimulate innovations in computers, control, and communications. New systems theory and mathematical techniques are then needed for analysis and design work.

As a broad-based department, Electrical, Computer, and Systems Engineering (ECSE) offers several advantages for undergraduate and graduate study. One is the ability to attack the many facets of modern problems that cut across disciplinary lines. Another is the flexibility for students to embark on individually tailored programs and for the department to launch new areas of research.

The department offers programs of study leading to bachelors, master's, and doctoral degrees in electric power engineering, electrical engineering, and computer and systems engineering. Each curriculum is sufficiently flexible to accommodate a wide range of interests. The curriculum the student selects is determined by his or her specific interests and, in some cases, by directions within a field of interest.

## Research and Innovation Initiatives

### Communications, Information, and Signal Processing

Advanced study and research in this field deals with the encoding, transmission, retrieval, and interpretation of information. Students may pursue programs of study strong in mathematical foundations, or oriented more toward hardware and practical implementation, or a combination of both.

Communications research focuses on the transmission of information over wireless, optical, and wire channels. Link level concerns, such as modulation and coding, as well as local and wide area networks are considered. Two of the fundamental subdisciplines emphasized are statistical communications and telecommunications. The former considers special types of systems in different environments, typified by random signals in random channels, as in space communication. The latter includes the hardware and societal demands of telephone, wireless communications, cable television, communications networks (including ATM and ISDN), and other systems.

The area of information processing is concerned primarily with the theory and engineering design associated with interpreting and manipulating received data, primarily in discrete form. Major research topics include information theory, including rate distortion theory, along with the coding and compression of speech, image, and video signals. A quantitative understanding of the nature and meaning of information provides a theoretical foundation. A special research emphasis at Rensselaer is the application of image transmission and interpretation techniques to pattern recognition, image processing, digital video, and speech recognition.

Signal processing considers the application of digital processing techniques to problems encountered in many areas, including biomedical instrumentation, control systems, and audio processing.

Special laboratories are available for speech processing, video and image processing, networking and communications.

### **Computer Networks**

Research focal areas in computer networking include network management, traffic management, congestion control, traffic engineering, quality-of-service (QoS) architectures, multimedia networking, network modeling, measurement, and performance analysis. The application areas include wired, wireless, ad-hoc, satellite networks, and pervasive computing. The networking group also participates in interdisciplinary research in control theory, economics, scalable simulation technologies, and video compression.

As world networks get increasingly complex, the need for automated network management and sophisticated traffic management capabilities becomes more urgent. The theoretical foundations for these areas are of immense interest. Moreover, the structure of the Internet in terms of thousands of ISPs demands new economic models and mechanisms to ensure continued investment and growth of Internet services. Network heterogeneity—especially in terms of wired, wireless, ad-hoc, and satellite—demands fundamental research for seamless interconnection. Rensselaer's modeling subgroup serves all areas in terms of self-similar and advanced stochastic models. Finally, newer applications with QoS capabilities need to be deployed on the Internet and co-exist with the current applications. The computer network group works on all these areas with a mix of analysis, simulation, and experimental tools.

### **Computer Vision, Image Processing, Geometry, and Digital Media**

Research in image processing covers a range of technologies and applications. This activity occurs at the Center for Image Processing Research (CIPR), the Center for Subsurface Sensing and Imaging Systems (CenSSIS), and the Center for Next Generation Video (CNGV), as well as the Document Analysis Laboratory (DocLab), Advanced Imaging Systems Laboratory, Computer Vision and Robotics Laboratory, and Intelligent Systems Laboratory.

Research areas include pattern recognition, computer vision, multidimensional and multimodality image analysis, image compression, biotech assay automation, eye tracking, optical scanning systems, artificial intelligence, graphics, computational geometry, and Internet image analysis services.

Application areas include computer-assisted surgery, radiation treatment planning, medical image reconstruction, document image analysis, geographic data analysis, and image analysis aids to neurobiology. Additional application areas are bioinformatics, human fatigue monitoring, human computer interaction, video imagery activity interpretation, decision making under uncertainty, robot localization, robotic devices for automated scoring of assays for the biotechnology industry, and biological multidimensional microscopy.

The work of digital media includes such topics as image processing algorithms and architectures for digital cinema, advanced image compression and decompression algorithms, and methods for indexing video by content. Multimedia work also includes graphics courseware development for the World Wide Web using HTML, Java, PHP, my SQL, and VRML.

### **Computer Hardware, Architecture, VLSI and Mixed Signal Design**

The design, implementation, layout, and testing of hardware systems constitute a vital component of computer engineering research. Research areas include multichip packaging concepts, high-frequency package characterization, thermal management, optical interconnections, and packaging reliability. Other topics include advanced concepts in fault tolerant computing, wafer-scale integration, high-speed GaAs RISC engines architectures for VLSI signal processing, and computer-aided design of VLSI for CMOS, bipolar, BiCMOS, and GaAs MESFET circuits. Fabrication and testing facilities are available in the Center for Integrated Electronics.

### **Control, Robotics, and Automation**

Current research projects address both the theory and application of control. Faculty interest in control theory includes adaptive control, large-scale systems, optimization, multivariable control, robust control, nonlinear control, model reduction, and discrete event systems. Design results are applied to robotics, advanced automation systems, flexible manufacturing, human physiology, large space structures, power systems, semiconductor systems, and material processing systems.

In robotics research, the focus is on intelligent robotic systems. Such systems represent a class of autonomous machines that can perform human-like functions with or without human interaction. They are fundamental for activities too hazardous for humans or too distant or complex for remote telemanipulation. This research is instrumental in advancing the theory of intelligent control with applications to systems of robotic arms. A robotic transporter with two-arm manipulative capabilities, stereo vision, and tactile sensing, connected to a Sun workstation network has been developed.

The design of controllers of large-scale systems is highly complex. Research is being performed on the design of low-order, structurally constrained robust controllers using iterative methods and convex programming techniques. Emphasis is also being given to linear and nonlinear model reduction methods. Applications to power systems, aircraft engines, and flexible structures are being considered, together with the development of control-aided design software.

Today, low-cost, highly reliable microcomputers and workstations that can be used for both control systems design and control system synthesis are widely available. As a result, increased emphasis has been placed on the design of implementable digital adaptive control logic that can be used for maintaining uniform qualities in an aircraft or other systems, despite large variations in the parameters that define the system dynamic equations. Such adaptive control algorithms have been developed and applied to a wide range of applications, including robotics, blood pressure control, large flexible systems, and flight control systems.

Discrete event systems theory is an emerging discipline relevant to communication protocols and parallel computing as well as manufacturing control. Petri net and formal language theory are being

developed to model, design, analyze, evaluate performance, and control such interconnected systems. Important issues are deadlock avoidance, synchronization, concurrency, resource allocation, and random events. Applications under study are manufacturing automation and integration, and task coordination for cooperating robotic systems.

All dynamic systems are fundamentally nonlinear. The nonlinearity can be either treated as a perturbation of a nominally linear system or directly taken into account in a nonlinear control design. In the first approach, linear control designs have been developed under various performance and robustness specifications. In the second approach, various nonlinear control strategies have been developed based on the Lyapunov theory, optimal control, and predictive control. There are currently various research projects applying these tools to a wide range of applications including vehicles, smart structures with piezoelectric actuators and sensors and shape memory alloy wires, robot position and force control, extrusion, and welding.

Research areas in robotics include sensor fusion, assembly sequence planning, dexterous manipulation, teleoperated and variably autonomous systems, distributed control architectures, and their applications to inspection, maintenance, and servicing operations in hazardous environments. Extensive experimental and computational facilities are available in the New York State Center for Automation Technologies.

In computer-aided design, research is focused on the front end of the manufacturing process, namely product development. The goal is to understand and develop computer-based systems to support initial conceptual design, feature-based design, geometric modeling, and rapid prototyping.

### **Electric Power and Power Electronics**

Current research is concentrated in five principal areas: electric and magnetic field computation, electrical transients and switching technology, dielectrics and insulation systems, power system analysis and optimization, and semiconductor power electronics.

The design of equipment to minimize losses, achieve compaction, or better utilize material frequently requires a sound knowledge of the electric and magnetic field configurations involved. Several projects in the recent past have adapted finite element methods to the solution of current problems in large machines. A new approach to digital field computations is being devised, based on techniques used to solve large network problems. The objective is to develop a more efficient, computationally conservative method. In today's energy-scarce world, there is a great emphasis on building more efficient electrical equipment. Projects are under way in the magnetic fields area to better understand the mechanism of electrical losses in rotating machinery and power transformers, with the ultimate goal of reducing these losses.

Of current interest are electric transients initiated by the switching of power plant auxiliaries and capacitor banks, especially by vacuum switching devices. The modeling of transients in transformer structures could also provide insight into the problems of both design and operation. The techniques being developed are finding application in new areas such as superconducting magnetic energy storage (SMES) and fault current limiting devices. This area of endeavor also includes the fundamental processes of switching large currents and the attendant system interactions.

An electrical insulation system, be it solid, liquid, gaseous, or a combination of these, is an essential part of all power equipment. Current research seeks to better understand the fundamental behavior of insulation under a variety of operating conditions and to develop diagnostic instrumentation. This involves experimentation and computer modeling in the areas of discharge physics, electrostatic phenomena, and high-voltage technology.

Optimization theory is used in the design of electric power systems to obtain high efficiency at minimum cost, particularly for systems that involve distributed generation. This has been extended to include the

development of intelligent protective relaying using the department's system simulator and Electromagnetic Transient Program (EMTP) studies.

With the development of innovative energy sources such as advanced electric machines, fuel cells, and solar photovoltaics, power electronic systems are playing an ever-increasing role at both the source and the load. Issues of power quality and electromagnetic interference (EMI) need to be addressed through careful circuit design, circuit board layout, and EMI resistant communications. Rensselaer has identified this growing area of interest and is currently investigating future solutions to these challenging problems.

With the continual improvement of power semiconductor devices over the last thirty years, it is now possible to convert electrical energy from one form to another efficiently and accurately. Work in this multidisciplinary field requires an understanding of semiconductor devices, circuit theory, signal analysis, analog and digital control, magnetics, and heat transfer. At Rensselaer, these fields are applied to electronic energy conversion and motion control for the electric power and industrial automation industries. Current interests include propulsion systems for electric vehicles, generation systems for wind turbines, the use of artificial intelligence (fuzzy logic, genetic algorithms, and neural networks) in the design and control of electric power conversion and electric machines, and the adaptive control of electric machines.

### **Microelectronics and Photonics Technology**

Advanced study and research includes semiconductor devices for power and high-frequency applications, fabrication of novel semiconductor materials and device structures, and the use and development of computer tools for microelectronics design. Research in association with the Center for Advanced Interconnect Sciences and Technology (CAIST) focuses on overcoming the strong limits interconnects pose for future developments in VLSI technology.

An extensive clean room in the Center for Integrated Electronics (CIE) is equipped for fabricating silicon-based devices, integrated circuits, and a full complement of equipment for compound semiconductor device processing. Activities in this area have been focused on novel device technology and process development, advanced interconnect processing, and the fabrication of micromechanical structures.

The microelectronics group has several specialized laboratories equipped to meet industrial standards for advanced research techniques. The electronic materials laboratory includes several state-of-the-art bulk crystal growth systems, wafer slicing and chemical mechanical polishing facilities, liquid phase epitaxy system for multilayer hetero-epitaxy growth, and cold wall epitaxial reactors for the growth of single crystal III-V and II-VI semiconductors. Diagnostic equipment available includes a scanning electron microscope with energy dispersive X-ray analysis, a double crystal X-ray diffractometer, a Fourier transform IR spectrometer, a photoluminescence system with visible and UV excitation, a spectroscopic ellipsometer, and a Hall-effect measurement system.

The high-voltage power device laboratory has equipment that can measure semiconductor power devices in wafer and package form up to 5000 V and 25 A. The equipment includes a Sony/Tektronix 370A curve tracer, an HP 4155 parameter analyzer with a high power module, a Velonex High Power Pulse Generator Model 350, a custom high-voltage rectifier and IGBT switching circuits, a 500 MHz digitizing oscilloscope, a Delta 9023 furnace, and a manual probe station with a high-temperature controller and chuck for device testing.

The semiconductor device characterization laboratories are equipped for carrying out comprehensive electrical characterization of semiconductor devices. Automated measurement systems are available for CV and IV measurements and deep level transient spectroscopy. Facilities are available for cryogenic

measurements of semiconductor and superconducting devices at liquid nitrogen and helium temperatures. Additional specialized instrumentation has been developed for analyzing the quantum efficiency and spectral response of solar cells and photoconductive materials, and automated reflectance, electroreflectance, and photorefectance for the characterization of semiconductor surfaces and quantum layers. Also available is a wide-band 35 GHz microwave setup for contactless measurement of electric resistivity, mobility, and excess carrier lifetime in epitaxial layers or bulk wafers. A full complement of microwave equipment is available for high frequency testing, including HP 8510 and 8410 network analyzers, frequency counters, probe stations, and an automated multiprobe system for on-wafer time-domain measurements.

Within the ECSE Department and the Center for Integrated Electronics are numerous Sun workstations with a variety of commercial design and simulation software, presently including Cadence, Mentor, TMA, and Hewlett-Packard software suites. Research programs developing supplemental design tools for modeling integrated circuits, devices, processes, and interconnects have provided unique supplemental capabilities.

### Plasma Engineering and Electromagnetics

Plasma engineering and electromagnetics have played fundamental roles in electrical engineering throughout the history of this discipline. Research at Rensselaer in recent years has centered on two general areas—analysis of electromagnetic fields and characterization of plasma media. Project areas include diagnostics for fusion plasmas based on the interaction between energetic particle beams and plasmas, the application of finite element methods to microwave heating of a variety of materials, antenna design, low temperature plasma modification of materials, magnetic levitation, and electric vehicles. Additional microwave projects are described in the section above.

High-temperature plasma research is crucial to the development of a controlled thermonuclear fusion energy source. Rensselaer's Plasma Dynamics Laboratory has a very active research program on the development of particle beam diagnostic systems for magnetically confined plasma experiments. Specific diagnostic techniques are developed and tested on relatively small-scale experiments in the on-campus laboratory. Techniques are then scaled up and applied on major confinement experiments located at other U.S. universities (e.g., the Universities of Texas and Wisconsin), at U.S. national laboratories (e.g., Oak Ridge National Lab and Lawrence Livermore National Lab), and foreign institutions (e.g., the Japanese National Institute for Fusion Science).

Electromagnetics remains one of the richest sources of problems and opportunities for electrical engineers. In recent years, the availability of powerful analysis tools, such as those based on finite element methods, has greatly enhanced the ability to exploit electromagnetic phenomena for the greater good of society. Issues associated with high power microwave antenna design, material properties assessment for microwave heating applications, noise in electric vehicle design, and processing of waste materials have been addressed.

## Faculty\*

### Professors

**Bhat, I.**—Ph.D. (Rensselaer Polytechnic Institute); solid state, electronic materials.

**Chow, J.H.**—PE., Ph.D. (University of Illinois); large-scale system modeling, multivariable control systems.

**Chow, T.P.**—Ph.D. (Rensselaer Polytechnic Institute); semiconductor device physics and processing technology, integrated circuits.

**Connor, K.A.**—Ph.D. (Polytechnic Institute of New York); electromagnetic theory, wave propagation, plasmas for fusion research and industrial applications, finite element methods.

**Degenoff, R.C.**—PE., D.Eng. (Rensselaer Polytechnic Institute); transient voltages in electrical

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

machines and transformers, HVDC system design and electric utility system planning.

- Desrochers, A.A.**—Ph.D. (Purdue University); discrete event dynamic systems, robotics, automated manufacturing systems control.
- Gerhardt, L.A.**—Ph.D. (State University of New York, Buffalo); communication systems, digital voice and image processing, adaptive systems and pattern recognition, integrated manufacturing.
- Gutmann, R.J.**—Ph.D. (Rensselaer Polytechnic Institute); solid-state devices, microwave techniques, and interconnection technology.
- McDonald, J.E.**—Ph.D. (Yale University); communication theory, coding and switching theory, computer architecture, integrated circuit design, high frequency packaging, digital signal processing.
- Nagy, G.**—Ph.D. (Cornell University); pattern recognition, document-image analysis, optical character recognition, geometric computation, computer-mediated learning, computer vision.
- Nelson, J.K.**—C.Eng., Ph.D. (University of London); dielectrics and insulation systems, computer-based diagnostics, electrostatic phenomena.
- Pearlman, W.A.**—Ph.D. (Stanford University); information theory and source coding; image, video, and audio compression; digital image and signal processing.
- Roysam, B.**—D.Sc. (Washington University); intelligent imaging at low SNR, parallel computation, biomedical applications.
- Salon, S.J.**—P.E., Ph.D. (University of Pittsburgh); machine design, system component modeling and simulation.
- Sanderson, A.C.**—Ph.D. (Carnegie Mellon University); robotics, knowledge-based systems, computer vision.
- Schubert, E.F.**—Ph.D. (University of Stuttgart); compound semiconductor devices and materials, light emitting diodes, heterobipolar transistors, semiconductor device physics, solid state lighting.
- Shur, M.S.**—D.Sc. (Ioffe Institute); semiconductor materials and devices, integrated circuit simulation, characterization and design.
- Tien, J.M.**—Ph.D. (Massachusetts Institute of Technology); systems modeling, queuing theory, public policy and decision analysis, computer performance evaluation, information systems, expert systems, computational cybernetics.
- Vastola, K.S.**—Ph.D. (University of Illinois); computer and communication networks.
- Wen, J.T.**—Ph.D. (Rensselaer Polytechnic Institute); nonlinear control, robot control, flexible structures control, deformation processes control.
- Woods, J.W.**—Ph.D. (Massachusetts Institute of Technology); digital signal processing, image processing, digital image and video compression.
- Wozny, M.J.**—Ph.D. (University of Arizona); computer graphics, computer-aided design, digital simulation, rapid prototyping systems.
- Zhang, X.-C.**—Ph.D. (Brown University); ultrashort optical pulse spectroscopy, terahertz lasers.
- Associate Professors**
- Franklin, W.R.**—Ph.D. (Harvard University); computational geometry, graphics and CAD applications, large geometric databases, geographic information systems, terrain visibility and compression.
- Kalyanaraman, S.**—Ph.D. (Ohio State University); ATM and Internet traffic management, multimedia networking, IP telephony, performance analysis, Internet pricing.
- LeCoz, Y.L.**—Ph.D. (Massachusetts Institute of Technology); numerical methods, random-walk algorithms for thermal and electromagnetic analysis of IC interconnects, quantum theory of semiconductor heterojunctions.
- Saulnier, G.J.**—Ph.D. (Rensselaer Polytechnic Institute); circuits and electronics, communication systems, digital signal processing.
- Schoch, P.M.**—Ph.D. (Rensselaer Polytechnic Institute); plasma diagnostics, instrumentation, engineering education.

**Stephanou, H.E.**—Ph.D. (Purdue University); multifingered robot hands, machine intelligence, neural networks, sensor fusion.

**Sun, J.**—Ph.D. (University of Paderborn); power electronics and energy systems.

**Xiang, N.**—Ph.D. (Ruhr-University Bochum); signal processing, acoustic sensing, and architectural acoustics.

#### **Assistant Professors**

**Abouzeid, A.A.**—Ph.D. (University of Washington); packet networks.

**Arcak, M.**—Ph.D. (University of California, Santa Barbara); design and analysis of nonlinear control systems, adaptive control, applications to mechanical systems.

**Dutta, P.S.**—Ph.D. (Indian Institute of Science); compound semiconductor materials and devices, crystal growth and substrate engineering, semiconductor quantum dots and nano-particles, photovoltaics, optoelectronics and microelectronics technologies.

**Huang, W.**—Ph.D. (Carnegie Mellon University); robotic manipulation, mobile robotics.

**Ji, Q.**—Ph.D. (University of Washington); computer vision, image processing, pattern recognition, robotics.

**Kar, K.**—Ph.D. (University of Maryland); routing and traffic management in computer networks, congestion control and fair resource allocation, ad-hoc and sensor networks.

**Mercado, A.V.**—Ph.D. (University of Maryland); wireless communication.

**Radke, R.J.**—Ph.D. (Princeton University); image and video processing.

**Sikdar, B.**—Ph.D. (Rensselaer Polytechnic Institute); computer networks.

**Yazici, B.**—Ph.D. (Purdue University); inverse problems in biomedical imaging, tomography, diffuse optical tomography, biomedical optics, free space optical communications, ultrasonics, statistical pattern recognition theory and application.

**Zhang, T.**—Ph.D. (University of Minnesota); VLSI signal processing, error-correcting coding.

#### **Clinical Professors**

**Murtuza, S.**—Ph.D. (Purdue University); engineering education.

#### **Research Associate Professors**

**Lu, J.**—Ph.D. (Technical University of Munich); electronic materials.

**Millard, D.L.**—Ph.D. (Rensselaer Polytechnic Institute); microelectronics design and manufacturing, nondestructive testing and evaluation, instrumentation systems, multimedia development.

#### **Research Assistant Professors**

**Azimi-Sadjadi, B.**—Ph.D. (University of Maryland); stochastic systems, control, communication.

**Demers, D.**—Ph.D. (Rensselaer Polytechnic Institute); fusion plasmas, plasma diagnostics.

**Gessmann, T.**—Ph.D. (University of Stuttgart); condensed matter, wide bandgap semiconductors.

#### **Adjunct Faculty**

**Anderson, T.R.**—Ph.D. (New York University); electromagnetic theory, antennas, electromagnetic compatibility.

**Berry, G.T.**—P.E., M.E. (Harvard University); power system operation.

**Blake, J.P.**—M.S. (Union College); software engineering.

**Bonissone, P.P.**—Ph.D. (University of California, Berkeley); theory of fuzzy sets.

**Bonner, S.J.**—Ph.D. (Rensselaer Polytechnic Institute); robotics.

**Caola, R.J.**—M.E. (Rensselaer Polytechnic Institute); protective relaying.

**Citriniti, T.D.**—M.S. (Rensselaer Polytechnic Institute); computer graphics and visualization.

**Ergene, L.T.**—Ph.D. (Rensselaer Polytechnic Institute), electromagnetics, electromechanical system component design and simulation.

**Hershey, J.E.**—Ph.D. (Oklahoma State University); communication systems, cryptography, intellectual property management.

**Kraft, R.P.**—Ph.D. (Rensselaer Polytechnic Institute); digital control and manufacturing systems.

**Marwali, M.K.**—Ph.D. (Illinois Institute of Technology); power transmission and generators.

**Merrill, H.M.**—P.E., Ph.D. (Massachusetts Institute of Technology); economic operation, planning and control of power systems.

**Michael, J.D.**—Ph.D. (Rensselaer Polytechnic Institute); plasma diagnostics, instrumentation, low pressure discharge modeling, laser diagnostics, novel light sources.

**Prabhakara, F.S.**—Ph.D. (Purdue University); power systems.

**Reichard, M.L.**—P.E., M.E. (Pennsylvania State University); industrial power systems.

**Sivasubramanian, K.**—Ph.D. (Rensselaer Polytechnic Institute); electromagnetics, machines.

**Thomenius, K.D.**—Ph.D. (Rutgers University); imaging science.

**Torrey, D.A.**—P.E., Ph.D. (Massachusetts Institute of Technology); semiconductor power electronics, electric machinery.

**Yuksel, M.**—Ph.D. (Rensselaer Polytechnic Institute); computer networks, Internet pricing, routing in wireless networks, large-scale network simulation.

#### **Emeritus Faculty**

**Borrego, J.M.**—P.E., Sc.D. (Massachusetts Institute of Technology); semiconductor device physics and characterization, solar cells, application of microwaves.

**Carlson, A.B.**—Ph.D. (Stanford University); communication systems, circuits and electronics, educational methods, social context of engineering.

**Close, C.M.**—Ph.D. (Rensselaer Polytechnic Institute); network analysis and synthesis, control systems.

**Das, P.K.**—Ph.D. (University of Calcutta); microwave acoustics, solid-state devices, integrated circuits.

**DiCesare, F.**—Ph.D. (Carnegie Mellon University); discrete event systems, Petri net theory and applications manufacturing automation and integration, traffic control.

**Frederick, D.K.**—Ph.D. (Stanford University); automatic control, process modeling and control, computer simulation.

**Ghandhi, S.K.**—Ph.D. (University of Illinois); solid-state materials and devices, integrated circuits, device technology and electronic circuits.

**Greenwood, A.N.**—Ph.D. (University of Leeds); electrical transients, interrupting devices.

**Hickok, R.L., Jr.**—Ph.D. (Rensselaer Polytechnic Institute); gaseous electronics, plasmas, energy conversion.

**Jennings, W.C.**—Ph.D. (Rensselaer Polytechnic Institute); plasma diagnostics, electronics manufacturing, multimedia educational materials.

**Kelley, R.B.**—Ph.D. (University of California, Los Angeles); methods to give machines smart behaviors, sensor-based automation/robotic systems, teaching methods.

**Norvik, E.J.**—M.E.E. (Rensselaer Polytechnic Institute); antennas, radio engineering, electronic circuits.

**Rose, K.**—Ph.D. (University of Illinois); semiconductor and superconductor materials and processing, VLSI design and testing.

**Saridis, G.N.**—Ph.D. (Purdue University); intelligent control systems, pattern recognition, computer systems, robotics, prostheses.

**Savic, M.**—Eng.Sc.D. (University of Belgrade); signal processing, biomedical electronics, electronics.

**Saxena, A.N.**—Ph.D. (Stanford University); solid-state materials, devices, integrated circuits, and advanced technologies.

#### **Senior Research Engineer**

**Schatz, J.G.**—A.A.S. (Hudson Valley Community College); vacuum and electronic systems.

## Undergraduate Programs

### Objectives of the Undergraduate Curriculum

The objectives of the programs in Electrical, Computer, and Systems Engineering are:

- To provide students with a foundation in mathematics, science, and engineering
- To provide students with the technical background needed for the practice of or for graduate study in, Electrical, Computer and Systems, or Electric Power Engineering. This background differs between the programs by having:
  - a. an emphasis on applied electro-physics, including electronics, electromagnetics and semiconductors, for Electrical Engineering, or
  - b. an emphasis on applied computer science, including data structures, computer architecture and software engineering, for Computer and Systems Engineering, or
  - c. an emphasis on electric power systems, including electromagnetics, electromechanics, and power semiconductor applications for Electric Power Engineering
- To prepare students to function in a professional environment, including the development of communication, leadership, and teamwork skills, the awareness of professional and ethical responsibility, and the preparation for life-long learning
- To provide students with a broad education including exposure to the humanities and social sciences
- To provide a learning environment that includes innovative pedagogical approaches and the access to current instrumentation and software tools

### Baccalaureate Programs

Within this department, students may obtain the Bachelor of Science degree in three disciplines, electrical engineering, computer and systems engineering, or electric power engineering. The department also encourages students to consider graduate study in any of these three curricula. A professional program option, which leads to both the B.S. and M.Eng. degree, is also open to qualified students.

Engineering design is introduced and developed in the required courses ENGR-2050, ENGR-2350, and ECSE-2610, and in various electives. These courses set the stage for capstone design experience in the design elective, a writing-intensive course that satisfies the Institute writing requirements.

The following program descriptions indicate course schedules for students who select any of the three ECSE disciplines as their chosen field of study. However, various arrangements can be made with the help of an adviser. In all cases, adviser approval of individual Plans of Study is necessary to ensure satisfaction of departmental and accreditation requirements. The adviser must also approve in writing any exceptions to the courses specified in the descriptions below.

All three of the ECSE curricula require completion of a minimum of 128 credit hours. Within all of these program areas, the Pass/No Credit option may be used only for humanities and social sciences electives (up to a maximum of six credits) or free electives. All other courses used to satisfy the degree requirements must be taken on a graded basis.

## Electrical Engineering Curriculum

Traditionally the largest and most diverse in all of engineering, this curriculum offers courses with various degrees of emphasis on theory, design, experimental work, and computer simulation. Subject matter ranges from semiconductors and electromagnetics to circuits and electronics, and to large-scale control, computer, communication, and information processing systems.

### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1
ENGR-1310	Intro. to Eng. Electronics <sup>1,2</sup> .....	1	MATH-1020	Calculus II .....	4
CHEM-1300	Chemistry Principles for Engineers....	4	CSCI-1100	Computer Science <sup>3</sup> .....	4
MATH-1010	Calculus I.....	4	PHYS-1100	Physics I.....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Second Year

Fall		Credit hours	Spring		Credit hours
ENGR-2050	Intro. to Engineering Design .....	4	ENGR-2350	Embedded Control .....	4
MATH-2400	Intro. to Differential Equations .....	4	ECSE-2010	Electric Circuits .....	4
PHYS-1200	Physics II.....	4	ECSE-2610	Computer Components and Operations <sup>3</sup> .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Third Year

Fall		Credit hours	Spring		Credit hours
ECSE-2050	Analog Electronics <i>or</i>		ECSE-2100	Fields and Waves I .....	4
ECSE-2060	Digital Electronics .....	4	ECSE-2210	Microelectronics Technology .....	4
ECSE-2410	Signals and Systems .....	4		Free Elective <sup>1,4</sup> .....	3-4
MATH-2010	Multivar. Calc. and Matrix Alg. <sup>1</sup> .....	4		Multidisciplinary Elective <sup>1</sup> .....	4
	Hum. or Soc. Sci. Elective <sup>1</sup> .....	4			

### Fourth Year

	Credit hours
ECSE-4500	Probability for Engineering Applications <sup>1</sup> .....
	Professional Development II <sup>5,6</sup> .....
ENGR-4010	Professional Development III .....
	Laboratory Elective .....
	Design Elective .....
	Restricted Elective .....
	Free Electives (2 or 3) <sup>4</sup> .....
	Concentration Electives (2) .....

<sup>1</sup> May be taken either term.

<sup>2</sup> May be replaced by ENGR-1300.

<sup>3</sup> Students entering this program in the fourth term should take CSCI-1100 in the spring, deferring ECSE-2610.

<sup>4</sup> The free electives must total at least 12 credits.

<sup>5</sup> This course will be fulfilled from a list published at the start of each semester.

<sup>6</sup> May be taken in the third year.

### Humanities or Social Sciences Electives

In this area, electives are based on the Institute and School of Engineering requirements. Additionally, at least one course must be selected from the list posted on the ECSE home page. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

### Restricted Elective

Any course with the designation EPOW, ECSE, or ENGR-4xxx.

#### Laboratory Electives

ENGR-4710	Advanced Manufacturing Laboratory I (Fall)
EPOW-4030	Electric Power Engineering Laboratory (Spring)
ECSE-4220	VLSI Design (Fall)
ECSE-4690	Experimental Networking (Fall)
ECSE-4760	Computer Applications Laboratory (Spring)
ECSE-4770	Computer Hardware Design (Fall)

#### Multidisciplinary Electives

ENGR-1600	Materials Science for Engineers
ENGR-2090	Engineering Dynamics
ENGR-2250	Thermal and Fluids Engineering I
ENGR-2530	Strength of Materials

### Design Electives

Design electives can be described as “multidisciplinary” (ECSE-4900) or “depth of understanding”. Students should visit the ECSE homepage for help with design elective selection.

ECSE-4900	ECSE Design (Fall and Spring)
ECSE-4120	Electronic Circuits Design (Spring)
ECSE-4260	Physical Design in Microelectronics (Spring)
ECSE-4560	Signal Processing Design (Spring)
ECSE-4980	Senior Design Project (Fall or Spring)
ECSE-6700	Advanced Computer Hardware Design (Spring)
ECSE-4460	Control Systems Design (Spring)

### Concentration Electives

Two courses in one of the concentration areas. See the ECSE homepage for areas and courses.

## Computer and Systems Engineering Curriculum

This field is one of the fastest-growing branches of engineering. Strong course sequences in software, hardware, and systems engineering are available. Students consider the digital computer as a system in itself, as a tool for modeling and design, and as an online element within a real-time system. There is the flexibility to study in depth automatic control, communications, or information processing, in addition to computer software, systems, and hardware.

### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1	MATH-2800	Intro. to Discrete Structures .....	4
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1310	Intro. to Eng. Electronics <sup>1,2</sup> .....	1
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
CSCI-1100	Computer Science I <sup>3</sup> .....	4	CSCI-1200	Computer Science II <sup>3</sup> .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Second Year

Fall		Credit hours	Spring		Credit hours
ENGR-2350	Embedded Control <sup>3</sup> .....	4	ECSE-2660	Computer Architecture, Networks, and Operating Systems <sup>3</sup> .....	4
ECSE-2610	Computer Components and Operations <sup>3</sup> .....	4	MATH-2400	Intro. to Differential Equations .....	4
CSCI-2300	Data Structures and Algorithms <sup>3</sup> .....	4	PHYS-1200	Physics II.....	4
PHYS-1100	Physics I.....	4	CHEM-1300	Chemistry Principles for Engineers....	4

### Third Year

Fall		Credit hours	Spring		Credit hours
ENGR-2050	Intro. to Engineering Design.....	4	ECSE-2410	Signals and Systems .....	4
ECSE-2010	Electric Circuits .....	4		Software Engineering Elective <sup>1</sup> .....	3-4
	Multidisciplinary Elective <sup>1</sup> .....	4		Free Elective <sup>1,4</sup> .....	3-4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4

### Fourth Year

	Credit hours	
	Professional Development II <sup>5,6</sup> .....	2
ECSE-4500	Probability for Engineering Applications <sup>1</sup> .....	4
ENGR-4010	Professional Development III.....	1
	Design Elective .....	3
	Restricted Elective .....	3-4
	Free Electives (2 or 3) <sup>4</sup> .....	8-9
	Concentration Electives.....	6-8
	Hum. or Soc. Sci. Elective .....	4

<sup>1</sup> May be taken either term

<sup>2</sup> May be replaced by ENGR-1300

<sup>3</sup> Students entering this program in the fourth term should take CSCI-1100 and ENGR-2350 in the spring deferring ECSE-2610, ECSE-2660, CSCI-1200, and CSCI-2300.

<sup>4</sup> The free electives must total at least 12 credits.

<sup>5</sup> This course will be fulfilled from a list published at the start of each semester.

<sup>6</sup> May be taken in the third year.

### Humanities or Social Sciences Electives

In this area, electives are based on the Institute and School of Engineering requirements. Additionally, at least one course must be selected from the list posted on the ECSE home page. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

### Restricted Elective

Any course with the designation ECSE, CSCI, or ENGR-4xxx.

#### Software Engineering Electives

ECSE-4690	Experimental Networking (Fall)
ECSE-4750	Computer Graphics (Fall or Spring)
ECSE-6770	Software Engineering I (Fall)
CSCI-4380	Database Systems (Fall or Spring)
CSCI-4440	Software Design and Documentation (Fall or Spring)
CSCI-4600	The Human-Computer Interface (Spring)

#### Multidisciplinary Electives

ENGR-1600	Materials Science for Engineers
ENGR-2090	Engineering Dynamics
ENGR-2250	Thermal and Fluids Engineering
ENGR-2530	Strength of Materials

### Design Electives

Design electives can be described as “multidisciplinary” (ECSE-4900) or “depth of understanding”. Students should visit the ECSE homepage for help with design elective selection.

ECSE-4900	ECSE Design (Fall and Spring)
ECSE-4460	Control Systems Design (Spring)
ECSE-4560	Signal Processing Design (Spring)
ECSE-4790	Microprocessor Systems Design (Fall)
ECSE-4980	Senior Design Project (Fall or Spring)
ECSE-4780	Advanced Computer Hardware Design (Spring)

### Concentration Electives

Two courses in one of the concentration areas. See the ECSE homepage for areas and courses.

## Electric Power Engineering Curriculum

The traditional place for electric power studies in a university is in the electrical engineering program, where the power option is offered as one of several concentrations. At Rensselaer, electric power is a separate degree program with its own faculty. It maintains strong ties to industry and is dedicated to preparing students for careers in power generation, delivery, or equipment; power electronics applied to drives and power conditioning; or at the intersection of electric power, economics, and management.

The vital role that energy plays in our lives has become increasingly evident in recent years. Society as we know it cannot function without an abundant supply of energy. It turns the wheels of industry and agriculture, it provides transportation, it supplies many of our domestic and recreational needs. There is continuing controversy over the primary source of the energy, but there is widespread agreement that electrical energy, because of its ease of transformation to and from other energy forms and its ease of transmission, distribution, and utilization, is vital. It is expected that electrical energy will constitute an increasing portion of the total energy used.

To keep pace with expanding needs through the development of ever more sophisticated systems requires the technical talent, scientific knowledge, mature judgment, and visionary innovation of the best

engineering minds of this generation. The electric power engineering program at Rensselaer is dedicated to meeting this need in generation, delivery, and utilization in an increasingly competitive environment. Study at Rensselaer is supported by the power industry, which the program serves. In particular, the ECSE Department operates a Grainger Scholar program under the auspices of the Grainger Foundation for well-qualified U.S. students.

### First Year

#### Fall

	Credit hours
MATH-2400	Calculus I.....4
CHEM-1300	Chemistry Principles for Engineers...4
ENGR-1100	Intro. to Engineering Analysis.....4
ENGR-1200	Eng. Graphics and CAD <sup>2</sup> .....1
	Hum. or Soc. Sci. Elective <sup>1</sup> .....4

#### Spring

	Credit hours
MATH-1020	Calculus II .....4
ENGR-1600	Materials Science for Engineers .....4
PHYS-1160	Physics I.....4
ENGR-1300	Engineering Processes <sup>2,3</sup> .....1
	Hum. or Soc. Sci. Elective <sup>1</sup> .....4

### Second Year

#### Fall

	Credit hours
MATH-2400	Intro. to Differential Equations .....4
PHYS-1200	Physics II.....4
ENGR-2050	Intro. to Engineering Design.....4
	Hum. or Soc. Sci. Elective <sup>1</sup> .....4

#### Spring

	Credit hours
ECSE-2010	Electric Circuits .....4
ENGR-4050	Modeling and Control of Dynamic Systems.....4
ENGR-2600	Modeling and Analysis of Uncertainty.....3
CSCI-1190	Beginning C Programming for Engineers .....1
	Hum. or Soc. Sci. Elective <sup>1</sup> .....4

### Third Year

#### Fall

	Credit hours
ENGR-4300	Electronic Instrumentation.....4
ECSE-2100	Fields and Waves I.....4
ENGR-2250	Thermal and Fluids Engineering I.....4
EPOW-4010	Power Engineering Fundamentals .....4

#### Spring

	Credit hours
ECSE-2410	Signals and Systems .....4
EPOW-4020	Electromechanics.....3
ENGR-2350	Embedded Control .....4
	Elective.....4
	Professional Development II <sup>6</sup> .....2

### Fourth Year

#### Fall

	Credit hours
EPOW-4080	Semiconductor Power Electronics.....3
	Technical Elective <sup>4</sup> .....3
	Hum. or Soc. Sci. Elective <sup>1</sup> .....4
	Elective.....4

#### Spring

	Credit hours
EPOW-4850	Electric Power Eng. Design .....3
EPOW-4030	EPE Laboratory.....4
	Elective.....4
	Technical Elective <sup>4</sup> .....3
ENGR-4010	Professional Development III <sup>5</sup> .....1

<sup>1</sup> There should be a total of 20 credit hours of H&SS electives.

<sup>2</sup> These required courses may be taken in any order.

<sup>3</sup> May be replaced by ENGR-1310.

<sup>4</sup> Any course in engineering or science that is at the 2000 level or higher.

<sup>5</sup> Can be taken in either semester during senior year.

<sup>6</sup> This course will be fulfilled from a list published at the start of each semester.

**Humanities or Social Sciences Electives**

In this area, electives are based on the Institute and School of Engineering requirements. Additionally, at least one course must be selected from the list posted on the ECSE home page. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

**Concentration in Power Electronics Systems**

The concentration in Power Electronics Systems is open to all students in Electric Power Engineering. Fulfillment of the concentration will be recognized by the department and consists of both the following courses:

- EPOW-4080 Semiconductor Power Electronics Systems
- EPOW-4850 Electric Power Engineering Design (with Power Electronics emphasis)

and one of the following:

- ECSE-4250 Integrated Circuit Processes and Design
- ECSE-4290 Electronic Packaging
- MANE-4490 Mechatronics
- MANE-4250 Mechatronic System Design

**Minor Programs**

Minors in any of the three ECSE curricula are open to undergraduates not majoring in any of these disciplines. The corresponding curriculum chair must approve all minors.

**In Electrical Engineering, the minor consists of:**

- ECSE-2010 Electric Circuits ..... 4
- ECSE-2410 Signals and Systems .....4
- ECSE-2610 Computer Components and Operations.....4
- Approved ECSE elective .....3-4

**In Computer and Systems Engineering, the minor consists of:**

- ECSE-2010 Electric Circuits .....4
- ECSE-2610 Computer Components and Operations.....4
- ECSE-2660 Computer Architecture, Networks, and Operating Systems .....4
- Approved ECSE elective .....3-4

**In Electric Power Engineering, the minor consists of:**

- ECSE-2010 Electric Circuits .....4
- ECSE-2050 Analog Electronics or ENGR-4300 Electronic Instrumentation.....4
- ECSE-2100 Fields and Waves .....4
- EPOW-4020 Electromechanics.....4
- EPOW-4010 Power Engineering Fundamentals or EPOW-4080 Semiconductor Power Electronics.....4

**Dual Major Programs**

These programs lead to a single baccalaureate degree embracing two fields. Special programs that can be completed in eight terms have been devised for:

- Electrical engineering and applied physics
- Electrical engineering and computer and systems engineering
- Electrical engineering and electric power engineering
- Computer and systems engineering and computer science

See the ECSE web page for detailed information about these programs.

## Professional Programs

ECSE students following the Electric Power Engineering Program may follow this option to complete both the B.S. and M.S. degrees. In this case, the fourth year follows closely the outline for the last year of the baccalaureate program. However, in choosing electives the student should bear in mind that the following courses must be taken at some time prior to or during the professional program:

ENGR-4760 Engineering Economics

Mathematics elective at 4000 level or higher

The following 4000-level courses (or their equivalents) can be used to satisfy the degree's mathematics course requirement:

MATH-4600 Advanced Calculus

MATH-4300 Intro. to Complex Variables: Theory and Applications

MATH-4500 Methods of Partial Differential Equations of Mathematical Physics

MATH-4700 Foundations of Applied Mathematics

The typical curricula for the remainder of the program is as follows:

### Fifth Year

Fall		Credit hours	Spring		Credit hours
EPOW-6810	Power Engineering Analysis .....	3	EPOW-6870	Mechanical Aspects of Electric Power Apparatus .....	3
EPOW-6850	Electric and Magnetic Fields in Electric Power Eng .....	3	EPOW-6890	Computer Methods in Electric Power Engineering .....	3
	Selected Power Courses <sup>1</sup> .....	3		Selected Power Courses <sup>1</sup> .....	3
	Electives .....	6		Electives .....	6

A student wishing to qualify for a B.S. degree by the end of the first year of professional school studies must complete the humanities and social sciences core requirement during the first year of the professional program.

## Special Undergraduate Opportunities

ECSE offers a couple of special programs for highly qualified students. These include:

### The Undergraduate Honors program

This program for outstanding undergraduates in electrical engineering or computer and systems engineering introduces research as a professional activity. All participants attend the ECSE Honors Seminar during their sophomore or junior year. Students also participate in at least one research project. An honors faculty adviser is assigned with whom special academic programs are developed that reflect the capabilities and interests of the exceptional student. Applications are accepted during a student's third semester or thereafter. Forms are available from the department curriculum office.

<sup>1</sup> At least two courses must be selected from the following:

EPOW-6820	Power Quality (Spring)	EPOW-6960	Topics in Electric Power Engineering (Spring or Summer)
EPOW-6880	Utility as a Business (Spring or Summer)	EPOW-6860	Surge Phenomena in Electric Power Engineering (Fall)
EPOW-6830	Protective Relaying (Fall; offered on availability of instructor)	ENVE-4400	Nuclear Power Systems Engineering (Spring)
EPOW-6840	Power Generation Operation and Control (Spring)		

### **The Grainger Scholar program**

This program is for well-qualified U.S. students in electric power engineering. Through this program, the power industry, under the auspices of the Grainger Foundation, supports study at Rensselaer.

## **Graduate Programs**

The department offers graduate programs leading to the Master of Engineering, Master of Science, Doctor of Philosophy, and Doctor of Engineering in all three of the department curricula. In all cases, particular emphasis is placed on developing a coherent individualized plan of study with the help of a faculty adviser.

### **Master's Programs**

Both the M.S. and the M.Eng. require 30 credits beyond the bachelor's degree.

#### **Master of Science**

This program is designed to prepare students for research-oriented careers and eventual pursuit of a doctoral degree. A six-credit thesis or project is usually required, but it may be waived for students who can submit a document of previous individual work that demonstrates equivalency in depth and presentation. Waivers are granted by the director of master's programs and must be replaced with six credit hours of course work.

The M.S. plans of study in electrical engineering and computer and systems engineering must consist of at least 18 credit hours of 6000-level courses and the thesis/project. At least 21 credit hours of ECSE courses must be taken, or up to six of these may be from a related technical area with the approval of the department. Programs that do not include 21 credit hours from ECSE must have prior approval from the director of master's programs. Students who do not have adequate preparation for their chosen area of specialization may need to take background courses in addition to the 30 credit hour requirement. An information sheet giving the requirements for several areas of specialization is available for all accepted students.

In the electric power engineering curricula, most study and research is of an applied nature, which is recognized in the awarding of the M.Eng. degree. However, courses and research directed more toward basic understanding of physical phenomena, such as the fundamental processes of electrical breakdown in dielectrics, can be pursued. This type of research would lead to the M.S. degree. This avenue also allows students with accredited degrees—not in engineering but perhaps in science—to obtain advanced degrees in the electric power area.

#### **Master of Engineering**

This one-year program is designed to prepare graduates for professional careers. Students entering the program typically hold accredited bachelor's degrees in appropriate branches of engineering. A master's thesis or project is not required.

The M.Eng. plans of study in electrical engineering and computer and systems engineering consist of at least 18 credit hours in 6000-level courses. In addition, it must include at least 21 credit hours in ECSE courses, or up to six of these may be from a related technical area with the approval of the department. Programs that do not include 21 credit hours from ECSE must have prior approval from the director of master's programs. Students who do not have adequate preparation for their chosen area of specialization may need to take background courses in addition to the 30 credit hour requirement. An information sheet giving the requirements for several areas of specialization is available for all accepted students.

The electric power engineering M.Eng. degree is a structured program of advanced professional study for the student holding an accredited bachelor's degree in the field or its equivalent in electrical engineering.

Course listings do not represent requirements except where indicated (see the fifth year requirements listed earlier); they are intended only to guide the student, who is encouraged to develop an individual program in consultation with his or her graduate adviser.

### **Doctoral Programs**

Advanced study and research for a Ph.D. or D.Eng. degree is conducted under the guidance of a thesis adviser representing the department. The student formulates an individual plan of study in consultation with the adviser. The doctoral qualifying examination should be taken prior to completing 15 credit hours beyond the master's degree. A minimum of 60 credit hours beyond the master's degree, including a dissertation, is required. The department expects the Institute requirements for candidacy and residency to be satisfied.

In the electric power engineering curricula, most study and research is of an applied nature, which is recognized in the awarding of the D.Eng. degree. However, courses and research directed more toward basic understanding of physical phenomena, such as the fundamental processes of electrical breakdown in dielectrics, can be pursued. This type of research would lead to the Ph.D. degree. This avenue also allows students with accredited degrees—not in engineering but perhaps in science—to obtain advanced degrees in the electric power area.

### **Special Graduate Opportunities**

In collaboration with the various campus centers and other departments, ECSE sponsors master's and doctoral program options in manufacturing systems and semiconductor technology. Descriptions of these programs are available upon request.

## **Course Descriptions**

Courses directly related to all Electrical, Computer, and Systems Engineering curricula are described in the Course Description section of this catalog under the department codes CSCI, DSES, ECSE, ENVE, EPOW, ITEC, MATH, MATP, MTLE, and PHYS.

# **Materials Science and Engineering**

**Chair:** David J. Duquette

**Undergraduate Advising:** Minoru Tomozawa

**Graduate Recruiting:** Roger N. Wright

**Graduate Advising:** Christoph Steinbruchel

**Department Home Page:** <http://www.eng.rpi.edu/dept/materials/>

Progress in modern technology is often limited by the availability of suitable solid materials. The materials engineer must produce materials to meet the demands of the designers of jet engines and rocket boosters, microelectronic devices, optical components, medical prostheses, and many other products.

The principles that govern the processing and structure of materials to produce optimum mechanical and physical properties and performance are embodied in the materials engineering curriculum. The program is designed to produce engineers and scientists whose degrees represent useful specialization coupled with a broad background in all classes of materials.

Undergraduate students wishing to extend their education can undertake specialized study in a range of fields. These include research in ceramics, polymers, composites, nanostructured materials, high-temperature alloys, solidification, corrosion, deformation processing, welding, high-strength high-modulus materials, biomaterials, electronic materials, surface and molecular kinetics, glass science, and the origin of mechanical and physical properties in many different types of materials. Graduate students, in addition to pursuing classroom courses, conduct research in a variety of areas described below and write their theses based on this research. Extensive laboratories containing modern and sophisticated equipment are available.

For the student who likes to innovate and who wants to apply knowledge to the real problems of a modern technological society, materials science and engineering provides a broad range of exciting opportunities.

## **Research and Innovation Initiatives**

### **Materials Processing**

Major research programs include fundamental studies of the solidification process and the effect of solidification under reduced gravity on the formation of dendritic structures, and practically oriented programs in the extrusion processing of aluminum alloys. In the latter program, studies of the complex interactions among stress, strain rate, and temperature during forming processes have made it possible to apply advanced software models to the control of metalworking operations. Studies of powder processing have made possible the extrusion processing of composite materials, while research on joining processes has led to synergistic coupling of adhesive bonding and spot welding technology in automotive sheet metal fabrication. New efforts focused on the synthesis, processing, and properties of nanostructured materials are expanding the capabilities of materials engineering and nanotechnology into additional areas including ceramics, metals, polymers, composites, and biomaterials. Novel applications of carbon nanotubes for device and chemical applications are under investigation, along with chemical, electrical, and mechanical isolation engineering using nanocomposites.

### **Materials for Microelectronic Systems**

This research concentrates on materials problems associated with the interconnections between integrated circuit elements. Included are the growth of thin films of metals and both polymer and ceramic dielectric materials, the patterning and etching processes necessary for the fabrication of multilayer devices, and the planarization processes necessary for successful device fabrication. Of special note is the program in microelectronics packaging, which addresses the mechanical, electronic, and thermal aspects of device design and fabrication.

### **Glasses and Ceramics**

Research efforts focus on factors influencing the useful lifetime of glass components and the effect of environments, especially aqueous environments, on glass failure. In addition to the conventional applications such as windows and bottles, glasses are used as optical components such as optical communication fibers. Specifically, variation of the glass surface structure with time and its influence on glass properties are under investigation. Another emphasis is the development of nonoxide glasses, primarily those based on fluorides, as the transmitting medium in optical fibers for communications purposes.

### **High-Performance Composite Materials**

These materials are used in industrial and consumer products due to their exceptional stiffness and strength-to-weight ratios. Applications of composites in the construction industry, such as steel bridge

repairs using graphite-epoxy composites, are growing rapidly. Meanwhile, next generation conceptual plans for hybrid electric vehicles are using ceramic composite components for gas turbine engines and thermal recuperators. Composites research activities at Rensselaer include ceramic, metallic, and polymer matrix composites; micromechanics and modeling of both fabrication processes and materials properties; design with new materials; synthesis of new matrix materials; and all aspects of the fabrication and characterization of composites and composite structures. Of special note is the sailplane program, in which students have designed, fabricated, and tested an all-composite glider, which has now been flying for over seven years. A new project, the composite hybrid electric vehicle, has also been initiated and offers numerous opportunities for both graduate and undergraduate participation.

## Faculty\*

### Professors

- Ajayan, P.M.**—Ph.D. (Northwestern University); synthesis, structure, and properties of carbon-based nanostructures and nanocomposites; phase transitions in nanoscale materials; electron microscopy.
- Duquette, D.J.**—Ph.D. (Massachusetts Institute of Technology); environmental and surface effects on the mechanical behavior of metals, corrosion, stress corrosion fatigue (Department Head).
- Glicksman, M.E.**—Ph.D. (Rensselaer Polytechnic Institute); melting and solidification, transport properties of liquid metals, phase transformation kinetics, metallurgy of superconductors (John Tod Horton Professor of Materials Engineering).
- Messler, R.W., Jr.**—Ph.D. (Rensselaer Polytechnic Institute); materials in manufacturing, welding.
- Nalamasu, O.**—Ph.D. (University of British Columbia); electronic and photonic polymers, nanopatterning, micro- and nanofabrication, electronic and photonic devices.
- Rajan, K.**—Sc.D. (Massachusetts Institute of Technology); electron microscopy, electronic materials, thin films and superlattices.
- Schadler, L.S.**—Ph.D. (University of Pennsylvania); polymer and glass matrix composites, micromechanical behavior, strains and interface properties, micro-Raman spectroscopy, environmental effects.
- Siegel, R.W.**—Ph.D. (University of Illinois); synthesis, processing, structure, and properties of functional nanostructured materials including metals, ceramics, and composites; biomaterials; atomic-scale defects and diffusion in materials (Robert W. Hunt Professor).
- Sternstein, S.S.**—Ph.D. (Rensselaer Polytechnic Institute); high-performance composites; physical properties of polymers; rubber elasticity theory; fracture, yielding, and craze formation in glassy polymers and composites, viscoelastic properties; swelling in filled elastomers (William Weightman Walker Professor of Polymer Engineering).
- Tomozawa, M.**—Ph.D. (University of Pennsylvania); electrical properties of glasses, X-ray and light scattering, phase separation, mechanical properties of glasses.
- Wright, R.N.**—Sc.D. (Massachusetts Institute of Technology); metal forming and fabrication, mechanical behavior of metals.

### Associate Professors

- Ramanath, G.**—Ph.D. (University of Illinois); thin film electronic materials; interconnects, diffusion barriers, low-k dielectrics; characterization of interfacial reactions, kinetics, and mechanisms of microstructure and phase evolution during deposition and annealing; processing self-organized structures for microelectronics applications.
- Steinbruchel, C.**—Ph.D. (University of Minnesota); thin films, electronic materials, plasma processing, ion beam and ultra-high vacuum techniques.

\* Departmental faculty listings are accurate as of the date generated for inclusion in this catalog. For the most up-to-date listing of faculty positions, including end-of-year promotions, please refer to the Faculty Roster section of this catalog, which is current as of the May 2004 Board of Trustees meeting.

**Assistant Professors**

**Gall, D.**—Ph.D. (University of Illinois, Urbana-Champaign); physical properties of thin films and nanostructures; combined theory, modeling and experimentation in thin film technology as applied to electronic structures and properties, transition-metal nitride film growth and characterization.

**Keblinski, P.**—Ph.D. (Pennsylvania State University); atomic mesoscopic-level computational modeling of interfacial processes; structure-property correlations; interfaces in silicon, diamond and metals; thin film growth; phase separation.

**Ozisik, R.**—Ph.D. (The University of Akron, Ohio); multiscale simulations of polymers, surface and interface properties of nanoparticles; development and characterization of fuel cells.

**Shima, M.**—Ph.D. (University of Maryland); thin film deposition; nano-patterning, structural and magnetic characterization.

**Research Professors**

**Doremus, R.H.**—Ph.D. (University of Cambridge), Ph.D. (University of Illinois); glass science, sintering of ceramics, bone implant materials, reactions in fused salts, crystallization, diffusion, optical properties of metals (New York State Science and Technology Foundation Professor of Glass and Ceramics Science).

**Hillig, W.B.**—Ph.D. (University of Michigan); ceramic and polymer matrix composites, strength of glass, crystal growth.

**Research Associate Professors**

**Lupulescu, A.**—Ph.D. (Rensselaer Polytechnic Institute); diffusion, crystal growth

**Emeritus Faculty**

**Chung, C.I.**—Ph.D. (Rutgers University); polymer processing, polymer melt theology, relaxation behavior in polymer solids.

**Ficalora, P.J.**—Ph.D. (Pennsylvania State University); kinetics and thermodynamics of heterogeneous reactions, chemisorption effects on electronic materials.

**Hudson, J.B.**—Ph.D. (Rensselaer Polytechnic Institute); adsorption on solid surfaces, structure and reactivity of solids, physics and chemistry of surfaces, nanocrystal growth.

**MacCrone, R.J.**—D.Phil. (University of Oxford); electric properties of polymers and oxides, polarons, electron paramagnetic resonance and magnetic behavior of glasses, phase transformations, nucleation, electrical properties of thin oxide and nitride films, one-dimensional conductivity.

**Moynihan, C.T.**—Ph.D. (Princeton University); ionic transport in glass, infrared transmission in glasses and glass ceramics, thermodynamic properties of glasses.

**Murarka, S.P.**—Ph.D. (University of Minnesota); Ph.D. (University of Agra); metallization for deep submicron silicon integrated circuits, low temperature and localized processes, thin dielectric films, diffusion and defects (Elaine S. and Jack S. Parker Chair in Engineering).

**Nippes, E.F.**—P.E., Ph.D. (Rensselaer Polytechnic Institute); physical metallurgy, welding metallurgy.

**Stoloff, N.S.**—Ph.D. (Columbia University); mechanical behavior of crystals, order-disorder reactions, fracture, stress corrosion.

**Manager of Electron Microscopy Facilities**

**Dove, R.**

**Manager of Instruction Laboratories**

**Van Steele, D.**

**Manager of Metallographic Facilities**

**Planty, R.**

## Undergraduate Programs

### Objectives of the Undergraduate Curriculum

While certain objectives of an undergraduate education in engineering are common to all programs, there are subtle but important differences that require some subset of objectives specific to ensuring that all graduates have specialized technical knowledge in their chosen field. In this regard, the Department of Materials Science and Engineering's baccalaureate program produces students who will:

- Exhibit general knowledge in all major classes of materials and specialized knowledge in several classes, such as metals, ceramics and glasses, polymers, composites and electronic materials
- Recognize the interdependence of the structure, properties, processing, and performance of materials and be able to integrate fundamental materials science with analysis of experimental data, laboratory synthesis and processing as well as quantitative modeling
- Integrate meaningful design experiences within Materials Engineering and in relationship to other engineering disciplines
- Exhibit a thorough grounding in fundamental mathematics and science and the ability to apply this knowledge in identifying, formulating, and solving real-life engineering problems
- Be able to put engineering problems, their solutions, and consequences into a societal context
- Effectively communicate and work in teams
- Maintain a desire for life-long learning

### Baccalaureate Program

The sample curriculum shown below, which results in the B.S. degree in Materials Engineering, requires a minimum of 128 credit hours and completion of the required elective courses that follow.

#### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis .....	4	ENGR-1300	Eng. Processes.....	1
MATH-1010	Calculus I .....	4	ENGR-1600	Materials Science for Engineers .....	4
CHEM-1300	Chemistry Principles for Engineers...	4	MATH-1020	Calculus II .....	4
	Hum. or Soc. Sci. Elective .....	4	PHYS-1100	Physics I .....	4
				Hum or Soc. Sci. Elective .....	4

#### Second Year

Fall		Credit hours	Spring		Credit hours
PHYS-1200	Physics II.....	4		Science Elective .....	4
MATH-2400	Intro. to Differential Equations .....	4	MTLE-2100	Structure of Materials .....	4
ENGR-2250	Therm./Fluid I .....	4	ENGR-2050	Intro. to Engineering Design .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
ENGR-1200	Engineering Graphics and CAD .....	1	CSCI-1190	Beginning C Programming for Engineers .....	1

**Third Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
ENGR-2600	Modeling & Anal. of Uncert. ....	3	MTLE-4250	Prop. of Eng. Materials II .....	4
MTLE-4200	Prop. of Eng. Materials I .....	4	MTLE-4150	Kinetics of Materials .....	4
MTLE-4100	Thermo. of Materials .....	4		Restricted Elective .....	4
	Professional Dev. II <sup>1</sup> .....	2		Free Elective I .....	4
	Hum. or Soc. Sci. Elective .....	4			

**Fourth Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
ENGR-4010	Professional Development III <sup>2</sup> .....	1	MTLE-4920	Appl. of Materials .....	2
MTLE-4910	Design in Materials Eng. ....	3	MTLE-4450	Materials Syn. and Proc. II .....	4
MTLE-4400	Materials Syn. and Proc. I .....	4		Materials Elective II .....	3
	Materials Elective I .....	3		Free Elective III .....	4
	Free Elective II.....	4			

**Electives**

The following is a list of courses from which the electives indicated above should be selected.

**Restricted Elective Options**

ENGR-2530	Strength of Materials
ENGR-2350	Embedded Control
ENGR-2090	Engineering Dynamics
ECSE-2010	Electric Circuits
ENGR-4300	Electronics Instrumentation

**Materials Electives**

MTLE-4030	Glass Science
MTLE-4050	Intro. to Polymers
MTLE-4160	Semiconducting Materials
MTLE-4290	Electronic Packaging
MTLE-4410	Welding Processes and Metallurgy
MTLE-4420	Joining of Advanced Materials
MTLE-4630	Composites Laboratory

**Minors Programs**

Students not majoring in materials science and engineering may receive a minor in this discipline by completing 15 credit hours of department courses with a MTLE designation.

**Graduate Programs**

The Department of Materials Science and Engineering offers programs leading to the M.S., M.Eng., and Ph.D. degrees.

**Master's Programs**

Both the M.S. and the M.Eng. require completion of a minimum of 30 credit hours.

**Master of Science**

For the M.S., students must complete 24 credits of course work, with at least 18 credits in materials courses. Three credits each are required in the areas of thermodynamics and kinetics, structure, and mechanical properties. Students who have not taken courses equivalent to undergraduate work at Rensselaer in X-ray diffraction, thermodynamics, mechanical properties, and their area of specialization must take graduate courses in these areas. Six credits of research work leading to an M.S. thesis are also required.

**Master of Engineering**

At least 21 credits of course work toward the M.Eng. degree must be materials courses. These must include one course each in structure and defects, thermodynamics and kinetics, and mechanical properties. A capstone independent study project is also required.

<sup>1</sup> This course will be fulfilled from a list published at the start of each semester.

<sup>2</sup> This course can be taken in either semester of senior year.

## Doctoral Programs

A minimum of 45 credits in course work is required for the Ph.D. degree in materials engineering. In addition to the course requirements for the M.S. degree, a minor of nine credits in a subject area outside the materials department is required. The student must pass an oral preliminary examination and an oral candidacy examination, as well as the final examination on the Ph.D. thesis.

## Course Descriptions

Courses offered by the Department of Materials Science & Engineering are described in the Course Description section of this catalog under the department code MTLE.

# Mechanical, Aerospace, and Nuclear Engineering

**Chair:** John A. Tichy

**Director, Mechanical Engineering:** John A. Tichy

**Director, Aerospace Engineering:** Zvi Rusak

**Director, Nuclear Engineering and Engineering Physics:** Don Steiner

**Associate Chair for Graduate Studies:** Antoinette Maniatty

**Associate Chair for Undergraduate Studies:** Henrik J. Hagerup

**Department Home Page:** [www.rpi.edu/dept/mane](http://www.rpi.edu/dept/mane)

Mechanical engineers are engaged in a wide range of activities. At one end of the spectrum, they are concerned with fundamental engineering science, especially energetics and mechanics. At the other end, they are involved with the hardware of various technologies—the design and manufacture of mechanical components and systems. Aerospace engineering is a branch of mechanical engineering with associated technologies that apply not only to aircraft and spacecraft, but to other vehicular systems such as submarines and hydrofoils as well. Nuclear engineering and engineering physics focus on the methods, devices, and systems required for the peaceful use of nuclear technology. While nuclear engineering's particular emphasis is on nuclear power generation, engineering physics emphasizes the radiation aspect of this technological area.

## Research and Innovation Initiatives

Opportunities for research and innovation are delineated below. Opportunities may be theoretical, computational, and/or experimental. The Flexible Manufacturing Center, the Center for Multiphase Research, the New York State Center for Automation Technologies, the Scientific Computation Research Center, and the Center for Integrated Electronics offer additional research opportunities for the department's undergraduate and graduate students and their faculty advisers.

### Aeronautics

Research is conducted into the performance of fixed wing aircraft, rotorcraft, and space vehicles, as well as micro-vehicles. The research is supported by fundamental studies in aerodynamics, advanced propulsion concepts, vehicle dynamics, and design optimization.

Facilities include the 4-by-6-foot subsonic wind tunnel, the transonic and supersonic blow-down wind tunnel, the 70-foot-long shock tube, the hypersonic shock tunnel, and the structures and controls laboratory.

**Applied Mechanics/Mechanics of Materials**

Applied Mechanics refers to the theoretical foundations of mechanical engineering. Basic research is being performed on diverse topics such as acoustics, fatigue and fracture processes, nonlinear vibrations, and plasticity. Materials of the latest technologies such as composites, microelectronic materials, and carbon nanotubes are studied from the mechanical perspective. The finite element method is a computational approach in modeling material behavior.

Facilities include the mechanics of materials laboratory, the laboratory for noise control research, and the mechanical systems laboratory.

**Energy Systems/Multiphase Phenomena and Heat Transfer**

Studies are related to energy conversion and the development of mechanical power, convective heat transfer and freezing, electronic cooling, fouling, heat transfer augmentation, mass transfer, computational fluid dynamics and multidimensional effects in multiphase flow, and heat transfer with applications in nuclear, mechanical, thermal, chemical, biomedical and pharmaceutical systems, development of mechanistic models, and computer simulation capabilities.

Facilities include the gas turbine laboratory; the energy systems laboratory; subsonic, transonic, and supersonic wind tunnels; shock tubes and the hypersonic shock tunnel; the heat transfer laboratory; and the laboratory for fouling research. Additional equipment includes various two-phase flow loops and associated instrumentation, laser Doppler anemometer, optical void probes, and the resources of the Center for Multiphase Research.

Mechanical and Nuclear Engineering are both concerned with energy conversion and the development of mechanical power. Issues of heat transfer are important, from a range of large-scale industrial processes, down to the cooling of electronic micro components with extreme power density. Thermal and fluid flow properties are studied by theoretical and computational means (computational fluid dynamics). Multiphase processes are important in problems from drug delivery optimization to nuclear power cooling systems. Facilities include the thermal fluids laboratory; subsonic, transonic, and supersonic wind tunnels; and the heat transfer laboratory. Additional equipment includes various two-phase flow loops and associated instrumentation, laser Doppler anemometer, etc.

**Environmental Health Physics and Radiation Dosimetry**

Research in this area has diverse applications: the assessment of environmental radioactivity for the nuclear industry; investigations of health physics practices in hospitals; analysis of worker effective doses from external and internal exposures; and optimization of radiation therapy doses in biomedical applications. These problems are studied theoretically by Monte Carlo methods, among several techniques. Facilities include a versatile health physics laboratory and modern nuclear radiation detection and characterization systems.

**Manufacturing/Design**

Studies revolve around design methodology in general and mechanical engineering design techniques in particular. There are applications in machinery and mechanical systems design, the development of new manufacturing techniques, and operation of manufacturing facilities. Areas of concentration include CAD/CAM, diagnostics and controls, tribology, metrology rapid prototyping, robotics and flexible manufacturing, and system integration. Facilities include the advanced manufacturing laboratory, the design optimization laboratory, the robotics and mechanisms laboratory, and the mechatronics laboratory.

**Nuclear Science and Technology**

Research involves a wide spectrum of issues crucial to the nuclear industries. Investigations are ongoing

into the interaction of neutrons and other radiation with materials used in nuclear reactors; nuclear data analysis and evaluation; radiation transport studies; conceptual designs of fusion power systems and their engineering, safety, and environmental implications; plasma wall interactions; analysis of reactor accidents and safety studies. Facilities include a versatile 100-Mev electron linear accelerator, time-of-flight and associated instrumentation, a critical reactor facility, a three-dimensional laser Doppler anemometer, and miscellaneous nuclear radiation equipment and computational aids.

### Space Technology

Research areas include analysis, design, development, and operations required for space exploration and utilization. Research is ongoing in advanced energetics (laser propulsion), structural dynamics and optimization, and crystal growth in space. Facilities include various supersonic wind tunnels, the shock tube, and crystal growth laboratories.

## Faculty\*

### Professors

- Crespo da Silva, M.R.M.**—Ph.D. (Stanford University); dynamics, nonlinear vibrations, perturbation methods, computerized symbolic manipulation.
- Drew, D.A.**—Ph.D. (Rensselaer Polytechnic Institute); applied mathematics, fluid mechanics (joint appointment, Mathematics home department).
- Dvorak, G.J.**—NAE, Ph.D. (Brown University); mechanics of solids, composite materials and structures, fracture and fatigue (William Howard Hart Professor of Mechanics).
- Fish, J.**—Ph.D. (Northwestern University); computational mechanics, finite element methods, micromechanics, mathematical modeling (joint appointment, Civil Engineering home department).
- Gabriele, G.A.**—Ph.D. (Purdue University); design automation, design optimization (Vice Provost for Administration, Dean of Undergraduate Education).
- Hajela, P.**—Ph.D. (Stanford University); optimum design, structural dynamics, aeroelasticity.
- Jensen, M.K.**—Ph.D., P.E. (Iowa State University); heat transfer, fluid mechanics, energy systems.
- Lahey, R.T., Jr.**—NAE, Ph.D., (Stanford University); multiphase flow and boiling heat transfer, reactor safety analysis, reactor thermal-hydraulics, applications of chaos theory (jointly with the Chemical Engineering Department; Edward W. Hood Jr. Professor).
- Li, C.J.**—Ph.D. (University of Wisconsin-Madison); control of manufacturing process and equipment, machine condition monitoring, nonlinear system identification.
- Malaviya, B.K.**—Ph.D. (Harvard University); fission and fusion reactor physics and technology, biomedical applications, radioactive waste management, pedagogic technology (jointly with Engineering Science).
- Ostrogorsky, A.G.**—Sc.D. (Massachusetts Institute of Technology); heat transfer and fluid mechanics, solidification, crystal growth (jointly with Materials Science and Engineering Department).
- Peterson, G.P. "Bud"**—Ph.D. (Texas A&M University); two phase heat transfer (Provost)
- Podowski, M.Z.**—Ph.D. (Warsaw University of Technology); two-phase flow and heat transfer, reactor dynamics and safety, system stability, applied mathematics.
- Rusak, Z.**—D.Sc. (Technion-Israel Institute of Technology); theoretical aerodynamics, fluid mechanics.
- Smith, R.N.**—Ph.D. (University of California, Berkeley); energy systems.
- Shephard, M.S.**—Ph.D. (Cornell University); finite element analysis, computer graphics, computer-aided design (jointly with the Civil Engineering Department; Samuel A. Johnson'37 and Elizabeth C. Johnson Professor of Engineering).
- Spilker, R.L.**—Ph.D. (Massachusetts Institute of Technology); biomechanics, finite element methods (joint appointment, Biomedical Engineering home department).

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**Steiner, D.**—Ph.D. (Massachusetts Institute of Technology); nuclear fusion systems, plasma engineering, radiation effects on materials (Institute Professor of Nuclear Engineering).

**Tichy, J.A.**—Ph.D. (University of Michigan); tribology, non-Newtonian fluid mechanics, rheology. (Department Chair)

**Tiersten, H.F.**—Ph.D., P.E. (Columbia University); continuum mechanics, continuum physics, electro-mechanical devices, structures.

#### **Associate Professors**

**Anderson, K.S.**—Ph.D. (Stanford University); multibody dynamics, parallel computing, vehicle dynamics.

**Blanchet, T.A.**—Ph.D. (Dartmouth College); tribology, solid lubrication, surface science, contact mechanics.

**Craig, K.C.**—Ph.D. (Columbia University); design, tribology, mechanics, controls (Chair, Engineering Science, and Director, Core Engineering).

**Derby, S.J.**—Ph.D. (Rensselaer Polytechnic Institute); automation, mechanisms, robotics, design.

**Embrechts, M.J.**—Ph.D. (Virginia Polytechnic Institute); fusion engineering, applied chaos theory, neural networks (joint appointment, Decision Sciences and Engineering Systems home department).

**Hagerup, H.J.**—Ph.D. (Princeton University); viscous flow.

**Hirsa, A.**—Ph.D. (University of Michigan); fluid mechanics, experimental gas dynamics.

**Huang, H.**—Ph.D. (University of California, Los Angeles); nanomechanics of materials, thin film deposition, radiation damage, multiscale materials modeling.

**Jansen, K.**—Ph.D. (Stanford University); computational mechanics, parallel computing, computational fluid dynamics.

**Kaminski, D.A.**—Ph.D. (Rensselaer Polytechnic Institute); heat transfer, computational fluid mechanics, thermal radiation.

**Maniatty, A.M.**—Ph.D. (Cornell University); continuum mechanics, mechanics of materials (Clare Boothe Luce Associate Professor).

**Messac, A.**—Ph.D. (Massachusetts Institute of Technology); optimal design, physical programming, design methodology, structural dynamics.

**Myrabo, L.N.**—Ph.D. (University of California, San Diego); energy systems, space technology.

**Picu, C.R.**—Ph.D. (Dartmouth College); mechanics of solids, micro- and nano-mechanics of crystalline defects, atomistic simulations.

**Scarton, H.A.**—Ph.D. (Carnegie Mellon University); biomechanics, wave phenomena, acoustics, noise control.

**Walczyk, D.F.**—Ph.D., P.E. (Massachusetts Institute of Technology); rapid tooling, environmentally conscious design, machine design.

**Xu, G.X.**—Ph.D. (Texas A&M University); environmental health physics, health and medical physics, Monte Carlo simulations, anatomical modeling, biomedical use of radiation (jointly with the Biomedical Engineering Department).

#### **Clinical Associate Professor**

**Alben, R.**—Ph.D. (Harvard); electronic materials, engineering education, engineering management, entrepreneurship, manufacturing and service operations.

**Steiner, M.W.**—Ph.D. (Rensselaer Polytechnic Institute); multidisciplinary design, product architecture, advanced design methods.

#### **Assistant Professors**

**Amitay, M.**—D.Sc. (Technion-Israel Institute of Technology); aerodynamics flow control, mini- and micro-unmanned aerial vehicles and two-phase flows with applications in medical engineering.

- Borca-Tasciuc, T.**—Ph.D. (University of California, Los Angeles); heat transfer and energy conversion, nanotechnology, MEMS.
- Castillo, L.**—Ph.D. (University at Buffalo); fluid mechanics, turbulent boundary layers.
- Danon, Y.**—Ph.D. (Rensselaer Polytechnic Institute); nuclear instrumentation and data, accelerator technology and radiation applications, nondestructive testing, neural networks applications.
- De, S.**—Sc.D. (Massachusetts Institute of Technology); numerical methods in engineering, multimodal virtual environments, fast computational techniques of MEMS.
- Koratkar, N.A.**—Ph.D. (University of Maryland at College Park); smart materials and structures, rotorcraft, unsteady aerodynamics.
- Peles, Y.**—Ph.D. (Technion-Israel Institute of Technology); MEMS fabrication, design and device testing, design and manufacturing of electronic packaging.

#### **Research Assistant Professors**

- Antal, S.**—Ph.D. (Rensselaer Polytechnic Institute); computational fluid dynamics, numerical methods in multiphase flows, heat transfer.

#### **Senior Lecturer**

- Swersey, B.L.**—B.S. (Cornell University); creativity in design, design methodology.

#### **Adjunct Faculty**

- Anderson, T.**—Ph.D. (New York University); plasma physics, fluid dynamics, reactor physics and radwaste management, environmental engineering.
- Borton, D.N.**—Ph.D. (Rensselaer Polytechnic Institute); solar energy.
- Caracappa, P.**—M.S. (Rensselaer Polytechnic Institute); radiation safety, health physics.
- DeLorey, T.E.**—Ph.D. (Massachusetts Institute of Technology); reactor physics, computational physics, software engineering.
- Feitelberg, A.S.**—Ph.D. (Massachusetts Institute of Technology); combustion.
- Francis, N.**—Ph.D. (University of Rochester); reactor physics.
- Haley, T.**—Ph.D. (Rensselaer Polytechnic Institute); nuclear fuel management, mathematical modeling, reactor design.
- Ting, J.K.**—M.S. (Massachusetts Institute of Technology); energy systems.
- Trumbull, T.H.**—M.Eng. (Rensselaer Polytechnic Institute); research reactor experimental operations.
- Witter, J.K.**—Ph.D. (Massachusetts Institute of Technology); reactor physics, plant operations, thermal hydraulics, reactor for space applications.

#### **Emeritus Faculty**

- Bergles, A.E.**—PE., NAE, Ph.D. (Massachusetts Institute of Technology); heat transfer, two-phase flow.
- Block, R.C.**—Ph.D. (Duke University); nuclear structure and data, radiation effects in electronics, accelerator technology neutron reactions, real-time radiography, industrial applications of radiation, nondestructive testing.
- Ettles, C.M.**—Ph.D. (Imperial College), D.Sc. (University of London); mechanical design, machine dynamics, tribology.
- Harris, D.R.**—Ph.D. (Rensselaer Polytechnic Institute); reactor physics, fusion technology, shielding, reactor noise analysis.
- Krempl, E.**—Dr.Eng. (Technical University of Munich); continuum mechanics; mechanics of materials; creep, fatigue, inelastic analysis (Rosalind and John J. Redfern Jr. Professor of Engineering).
- Lee, D.**—Sc.D. (Massachusetts Institute of Technology); mechanics of materials, computer-aided manufacturing.
- Nagamatsu, H.T.**—Ph.D. (California Institute of Technology); hypersonics, transonics, plasma dynamics, aeroacoustics, heat transfer.

**Sneck, H.J., Jr.**—Ph.D., P.E. (Rensselaer Polytechnic Institute); viscous-fluid mechanics, bearing lubrication and design.

**Somerscales, E.F.C.**—Ph.D. (Cornell University); heat transfer.

### Technical Support Staff

**Brand, P.**

**Calabrese, S.J.**

**Caracappa, P.**

**Gray, M.**

**McDougall, R.**

**Mielke, W.R., Jr.**

**Murray, S.F.**

**Paedelt, V.**

**Prince, L.**

**Stephens, J.**

**Trumbull, T.**

**Westhead, J.**

## Undergraduate Programs

### Objectives of the Undergraduate Curriculum

While certain objectives of an undergraduate education in engineering are common to all programs, there are subtle but important differences that require some subset of objectives specific to ensuring that all graduates have specialized technical knowledge in their chosen field. In this regard, graduates of the Department of Mechanical, Aerospace, and Nuclear Engineering's baccalaureate program will:

- Be able to apply skills in science and mathematics to the practice of engineering.
- Through a broad education in the humanities and social sciences, be able to identify and treat problems of interest to society.
- Have the ability to analyze real-world problems and to design products and systems for their solution.
- Develop strong communication skills both oral and written.
- Exhibit teamwork skills and leadership ability, working both within specialized and multidisciplinary settings, and form an awareness and appreciation of ethical and societal implications and the impact of engineering solutions in a global context.
- Have a broad foundation in mechanical systems, thermal and fluids engineering, and electronics and controls; be able to apply their knowledge to the design of mechanical and thermal/fluids systems and devices; gain additional technical depth in one or more areas of concentration, such as aeronautics, applied energy systems, design optimization, dynamics, heat transfer and fluid mechanics, manufacturing, mechatronics, and mechanics of materials; and be familiar with basic laboratory techniques in mechanical and in thermal/fluids engineering ; or
- Have a broad foundation in aerodynamics, aircraft structures, propulsion, and flight mechanics; be able to design and conduct experiments; and be familiar with basic numerical methods for engineering problems and the use of high-level computer software ; or
- Develop and demonstrate the ability to apply relevant atomic and nuclear phenomena to nuclear and radiological systems and processes, conduct experimental investigations, and work on design projects so as to be prepared to work professionally in one or more of the nuclear or radiological fields of specialization identified by the nuclear engineering program ; or
- Have a broad foundation in the application of engineering to physical systems and additional depth in one or more areas of concentration such as multiphase science, radiation technology, microelectronics, and applied mathematics; conduct experimental and analytical investigations and design projects; and develop the ability to work professionally in one or more of the areas of specialization identified by the engineering physics program.

- Be motivated for continued intellectual growth and improvement in engineering skill beyond graduation.

Students may achieve these objectives through completion of the B.S. degree in mechanical engineering, aerospace engineering, nuclear engineering, or engineering physics. A variety of options are available to those pursuing the B.S., depending upon the specific degree program. These options, which include concentrations, minors, and/or dual majors are delineated within the following individual descriptions of each baccalaureate curriculum.

### Baccalaureate Programs

Freshmen or sophomores who have identified mechanical, aerospace, nuclear engineering, or engineering physics as their major may follow the baccalaureate program below in lieu of the general core engineering program presented earlier. The total number of credit hours required to complete any of these curricula is 128. Dual major programs which lead to a single baccalaureate degree embracing two fields are also available and are described in more detail below.

### Mechanical Engineering Curriculum

#### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1300	Engineering Processes <sup>12</sup> .....	1
ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1	ENGR-1600	Materials Science for Engineers.....	4
CHEM-1300	Chemistry Principles for Engineers....	4	MATH-1020	Calculus II.....	4
MATH-1010	Calculus I.....	4	PHYS-1100	Physics I.....	4
	Hum. or Soc. Sci. Elective.....	4		Hum. or Soc. Sci. Elective.....	4

#### Second Year

Fall		Credit hours	Spring		Credit hours
ENGR-2530	Strength of Materials.....	4	ENGR-2050	Intro. to Engineering Design.....	4
MATH-2400	Intro. to Differential Equations.....	4	ENGR-2090	Engineering Dynamics.....	4
PHYS-1200	Physics II.....	4	ENGR-2250	Thermal and Fluids Engineering I.....	4
	Hum. or Soc. Sci. Elective.....	4		Hum. or Soc. Sci. Elective.....	4
			CSCI-1190	Beginning C Programming for Engineers.....	1

#### Third Year

Fall		Credit hours	Spring		Credit hours
ENGR-2600	Modeling and Analysis of Uncertainty.....	3	ENGR-2350	Embedded Control.....	4
ENGR-4300	Electronic Instrumentation.....	4	ENGR-4050	Modeling and Control of Dynamic Systems.....	4
	Mechanical Engineering Core Module <sup>3</sup> .....	6		Mechanical Engineering Core Module <sup>3</sup> .....	6
	Hum. or Soc. Sci. Elective.....	4		Professional Development II <sup>4</sup> .....	2

<sup>1</sup> These required courses may be taken in any order.

<sup>2</sup> Alternative: ENGR-1310

<sup>3</sup> Choice of Mechanical Design Module and Thermal and Fluids Module. Both modules are required for graduation; each module may be taken in either semester. The Mechanical Design Module consists of MANE-4030 and MANE-4040, taken concurrently. The Thermal and Fluids Module consists of MANE-4010 and MANE-4020, taken concurrently. Other third year courses may be taken in either semester.

<sup>4</sup> This course will be fulfilled from a list published at the start of each semester. It must be completed before MANE-4260.

## Fourth Year

### Credit hours

MANE-4260	Design of Mechanical Engineering Systems.....	3
ENGR-4010	Professional Development III <sup>5</sup> .....	1
	Concentration Elective (Restricted)....	3
	Concentration Elective (Restricted)....	3
	Concentration Elective.....	3
	Concentration Elective.....	3
	Free Elective .....	4
	Free Elective .....	4
	Free Elective .....	4

### Concentrations

The mechanical engineering curriculum offers the following six concentration options.

#### *Aeronautics*

The focus is on the analysis, design, development, and operation of flight vehicles, which is fundamental for students interested in aeronautical engineering. This concentration provides a strong engineering and scientific foundation in fluid mechanics, thermodynamics, structural dynamics, vehicular mechanics, and control systems analysis. Student projects in recent years have involved spin preventions in fighter aircraft, trailing vortex dissipation, and helicopter maneuverability.

#### *Applied Mechanics*

This concentration provides the opportunity for fundamental study in fluid mechanics and solid mechanics. The objective is to develop broad analytical abilities and encourage critical inquiry. Programs in this area usually continue through the master's level. Topics have included cellular heat convection, locally separated flow, and inelastic fatigue analysis and fracture. Biomechanics, especially the mechanics of musculoskeletal systems, is part of this concentration.

#### *Design*

The concern here is with design methodology in general and mechanical design techniques in particular, and is intended for mechanical engineering students interested in the design of machinery and mechanical systems. A student interested in the design of specialized mechanical equipment can develop a suitable program from courses in this and other mechanical engineering concentrations.

#### *Energy Systems*

This concentration is intended for those interested in energy conversion and the development of mechanical power. Students concerned with the design of equipment in this field should consider this concentration together with the design concentration. Those interested in the fundamentals should consider this concentration together with the applied mechanics concentration.

#### *Manufacturing Concentration*

This area is intended for the mechanical engineering student who is interested in manufacturing and is planning a career designing manufacturing equipment, developing new manufacturing techniques, or operating manufacturing facilities.

#### *Space Technology*

This is an inherently multidisciplinary area that is offered for students interested in the analysis, design,

<sup>5</sup> Can be taken either semester senior year.

development, and operations required for space exploration and utilization. Current areas of particular emphasis include the space environment, propulsion, orbital and structural dynamics, structures and control.

### Concentration Electives Criteria

Students wishing to obtain any one of these concentrations must adhere to strict concentration electives criteria as follows. The first two courses within the four-course concentration are highly restricted. The first of these should be selected from the courses listed below. These courses define the concentration areas available within mechanical engineering and are thus termed “concentration-defining” electives.

#### Applied Mechanics

- MANE-4670 Mechanical Behavior of Materials I
- MANE-4170 Machine Dynamics
- MANE-4610 Vibrations

#### Aeronautics

- MANE-4070 Aerodynamics I
- MANE-4060 Aerospace Structural Analysis

#### Design

- MANE-4280 Design Optimization
- MANE-4180 Mechanisms

#### Energy Systems

- MANE-4710 Advanced Heat Transfer
- MANE-4720 Design and Analysis of Energy Systems

- MANE-4800 Boundary Layers and Heat Transfer

#### Manufacturing

- MANE-4550 Analysis of Manufacturing Processes
- ENGR-4710 Advanced Manufacturing Laboratory I

#### Mechatronics

- MANE-4490 Mechatronics

The second of the restricted concentration elective courses may be chosen from either:

- A list of courses associated with the originally defined concentration area. Such courses will be termed “concentration-completing” electives. Through them, a student clearly identifies a concentration within the mechanical engineering major.
- The original short list of concentration-defining electives. Through these, a student obtains greater breadth within mechanical engineering.

Any student wishing to satisfy these restricted concentration elective requirements in another way may first consult with the adviser and then propose a plan to the associate chair in undergraduate studies for approval. Students are reminded to consult the catalog and the *Class Hour Schedule* for the availability of a particular course in any given semester.

The second two courses of the four-course concentration are to be selected from any upper-level (4000 or above) course in science, engineering, or mathematics. One of these may be an independent study course, such as a design project or an undergraduate research project. The second course should not normally be a project. However, the associate chair for undergraduate studies may grant approval for an exception based on a particularly valuable research experience.

### Humanities or Social Sciences Electives

In this area, the electives are based on the Institute and School of Engineering requirements. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

### Dual Major Programs

Dual majors lead to a single baccalaureate degree embracing two fields. Special programs which can be completed in eight semesters have been developed. Examples include dual majors in Mechanical

Engineering and Aerospace Engineering, Mechanical Engineering and Biomedical Engineering, Mechanical Engineering and Nuclear Engineering, Mechanical Engineering and Product Design and Innovation (STS), and others. Further information is available in the departmental office.

## Aerospace Engineering Curriculum

### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	ENGR-1300	Engineering Processes <sup>1,2</sup> .....	1
ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1		Hum. or Soc. Sci. Elective .....	4
CHEM-1300	Chemistry Principles for Engineers....	4	MANE-2060	Fundamentals of Flight .....	4
	Hum. or Soc. Sci. Elective .....	4	MATH-1020	Calculus II .....	4
MATH-1010	Calculus I.....	4	PHYS-1100	Physics I.....	4

### Second Year

Fall		Credit hours	Spring		Credit hours
ENGR-2530	Strength of Materials .....	4	ENGR-2050	Intro. to Engineering Design.....	4
	Hum. or Soc. Sci. Elective .....	4	ENGR-2090	Engineering Dynamics .....	4
MATH-2400	Intro. to Differential Equations .....	4	ENGR-2250	Thermal and Fluids Engineering I....	4
PHYS-1200	Physics II.....	4		Hum. or Soc. Sci. Elective .....	4
			CSCI-1190	Beginning C Programming for Engineers .....	1

### Third Year

Fall		Credit hours	Spring		Credit hours
ENGR-2600	Modeling and Analysis of Uncertainty .....	3	ENGR-4050	Modeling and Control .....	4
MANE-4060	Aerospace Structural Analysis .....	3	MANE-4030	Elements of Mechanical Design .....	4
MANE-4070	Aerodynamics I.....	3	MANE-4900	Aeroelasticity and Structural Vibration .....	3
MATH-4800	Numerical Computing .....	4	MANE-4920	Aerospace Structures and Controls Laboratory .....	2
	Professional Development II <sup>3</sup> .....	2		Hum. or Soc. Sci. Elective .....	4

### Fourth Year

Fall		Credit hours	Spring		Credit hours
ENGR-4010	Professional Development III <sup>4</sup> .....	1		Capstone Design Elective <sup>6</sup> .....	3
MANE-4080	Propulsion Systems .....	4		Free Elective .....	4
MANE-4800	Boundary Layers and Heat Transfer ..	3		Free Elective .....	4
	Flight Mechanics Elective <sup>5</sup> .....	4		Free Elective .....	4
MANE-4910	Fluid Dynamics Laboratory .....	2			

### Humanities or Social Sciences Electives

In this area, the electives are based on the Institute and School of Engineering requirements for these electives. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social

<sup>1</sup> These required courses may be taken in any order.

<sup>2</sup> Alternative: ENGR-1310.

<sup>3</sup> This course will be fulfilled from a list published at the start of each semester.

<sup>4</sup> Can be taken either semester senior year.

<sup>5</sup> Choice of: MANE-4090, MANE-4100, or MANE-4200.

<sup>6</sup> Choice of: MANE-4230, MANE-4850, or MANE-4860.

Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

### Dual Major Programs

A dual major in Aerospace Engineering and Mechanical Engineering is available to students who follow a prescribed program that can be completed in eight semesters. These students would choose ENGR-1600, ENGR-2350, ENGR-4300, and MANE-4040 as free electives. General requirements and procedures for dual degrees are described within the Academic Information and Regulations section of this catalog.

### Nuclear Engineering Curriculum

#### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. to Engineering Analysis.....	4	PHYS-1100	Physics I .....	4
MATH-1010	Calculus I.....	4	MATH-1020	Calculus II .....	4
CHEM-1300	Chemistry Principles for Engineers....	4	ENGR-1600	Materials Science for Engineers .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1	ENGR-1300	Engineering Processes or	
			ENGR-1310	Intro. to Eng. Electronics <sup>1</sup> .....	1

#### Second Year

Fall		Credit hours	Spring		Credit hours
PHYS-1200	Physics II .....	4	ENGR-2600	Modeling and Analysis of	
MATH-2400	Intro. to Differential Equations .....	4		Uncertainty .....	3
	Free Elective I .....	4	ENGR-2830	Nucl. Phenomena for Eng. Appl. ....	4
	Hum or Soc. Sci. Elective .....	4	ENGR-2050	Intro. to Eng. Design <sup>2</sup> .....	4
				Hum. or Soc. Sci. Elective .....	4
			CSCI-1190	Beginning C Programming for	
				Engineers .....	1

#### Third Year

Fall		Credit hours	Spring		Credit hours
ENGR-2250	Thermal and Fluids Eng. I .....	4	MANE-4400	Nucl. Power Systems Engineering ....	4
ENGR-4300	Electronic Instrumentation .....	4	MANE-4480	Physics of Nuclear Reactors .....	4
MANE-2400	Fundamentals of Nuclear Eng. ....	4	MANE-4470	Radiological Engineering .....	4
	Hum. or Soc. Sci. Elective .....	4		Professional Development II .....	2
				Technical Elective <sup>3</sup> .....	3

#### Fourth Year

Fall		Credit hours	Spring		Credit hours
ENGR-4050	Mod. and Control of Dynamic Sys. ...	4		Restricted (NE) Elective I .....	3
MANE-4370	Nuclear Engineering and Eng. Physics			Technical Elective II <sup>3</sup> .....	3
	Lab. ....	4		Restricted (NE) Elective II .....	3
	Free Elective II .....	4	MANE-4390	Senior Design Project II .....	2
MANE-4380	Senior Design Project I .....	1		Free Elective III .....	4
ENGR-4010	Professional Development III <sup>4</sup> .....	1			

<sup>1</sup> May be taken in any order in the first two semesters.

<sup>2</sup> Includes Professional Development I.

<sup>3</sup> Any course in engineering or science at 4000 level or higher.

<sup>4</sup> Can be taken either semester senior year.

## **Concentrations**

For more information on any of these concentrations, students should consult with their program adviser.

### ***Reactor Physics***

This area of concentration is intended for students who wish to develop expertise in the physics of nuclear power reactor cores. Topics such as reactor physics design, nuclear fuel management, and reactor startup physics tests are included.

### ***Reactor Engineering***

This area of concentration is intended for students who wish to develop a broad understanding of nuclear technology. Topics such as reactor thermal-hydraulics, reliability, safety and licensing, radioactive waste management, structural dynamics, and materials problems are included.

### ***Health Physics***

This area of concentration is intended for students who wish to develop expertise in the radiation safety aspects of nuclear power plant operations and the associated nuclear fuel cycle.

### ***Nuclear Thermal Hydraulics***

This area of concentration is intended for students who wish to develop an extended knowledge and the ability to apply principles of fluid mechanics and heat transfer in single-phase and multiphase gas-liquid systems to reactor engineering.

### ***Nuclear Plant Operations and Management***

This area of concentration is intended for students who wish to specialize in the operation and management of nuclear power plants. This concentration is directed toward students interested in careers with nuclear electric utility organizations.

### ***Fusion Reactor Engineering***

This area of concentration is intended for students who desire to develop expertise in the analysis, assessment, and design of fusion reactor power systems.

## **Humanities or Social Sciences Electives**

In this area, the electives are based on the Institute and School of Engineering requirements. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

## **Dual Major Programs**

Dual major programs in Nuclear Engineering and Mechanical Engineering, and in Nuclear Engineering and Engineering Physics, are available to students who follow prescribed programs that can be completed in eight semesters. Further information is available in the departmental office.

## **Minor Programs**

Students not majoring in nuclear engineering may receive a minor in this discipline by completing 15–16 credit hours of study selected in consultation with their program adviser.

## Engineering Physics Curriculum

### First Year

Fall		Credit hours	Spring		Credit hours
ENGR-1100	Intro. To Engineering Analysis .....	4	PHYS-1100	Physics I.....	4
MATH-1010	Calculus I .....	4	MATH-1020	Calculus II .....	4
CHEM-1300	Chemistry Principles for Engineers....	4		Science Elective <sup>2</sup> .....	4
	Hum. or Soc. Sci. Elective .....	4		Hum. or Soc. Sci. Elective .....	4
ENGR-1200	Eng. Graphics and CAD <sup>1</sup> .....	1	ENGR-1300	Engineering Processes or	
			ENGR-1310	Intro. to Eng. Electronics <sup>1</sup> .....	1

### Second Year

Fall		Credit hours	Spring		Credit hours
PHYS-1200	Physics II.....	4	ENGR-2600	Modeling and Analysis of	
MATH-2400	Intro. to Differential Equations .....	4		Uncertainty .....	3
	Free Elective I.....	4	ENGR-2830	Nucl. Phenomena for Eng. Appl. ....	4
	Hum. or Soc. Sci. Elective .....	4	ENGR-2050	Intro. to Eng. Design <sup>1</sup> .....	4
				Hum. or Soc. Sci. Elective. ....	4
			CSCI-1190	Beginning C Programming for	
				Engineers .....	1

### Third Year

Fall		Credit hours	Spring		Credit hours
ENGR-2250	Thermal and Fluids Eng. I.....	4	MANE-4400	Nucl. Power Systems Engineering .....	4
ENGR-4300	Electronic Instrumentation.....	4	MANE-4470	Radiological Engineering .....	4
MANE-4410	Appl. Atomic Nucl. Physics .....	4		Hum. or Soc. Sci. Elective .....	4
	Restricted (EP) Elective I.....	4		Professional Development II .....	2
				Technical Elective I <sup>4</sup> .....	3

### Fourth Year

Fall		Credit hours	Spring		Credit hours
ENGR-4050	Mod. and Control of Dynamic Sys. ...	4		Restricted (EP) Elective II .....	3
MANE-4370	Engineering Physics Lab.....	4		Restricted (EP) Elective III .....	3
	Free Elective II.....	4		Technical Elective II <sup>4</sup> .....	3
MANE-4380	Senior Design Project I .....	1	MANE-4390	Senior Design Project II .....	2
ENGR-4010	Professional Development III <sup>5</sup> .....	1		Free Elective III .....	4

<sup>1</sup> May be taken in any order in the first two semesters.

<sup>2</sup> Science Elective: ENGR-1600 or CSCI-1100 (C Programing not necessary after Computer Science I).

<sup>3</sup> Includes Professional Development I.

<sup>4</sup> Any course in engineering or science at 4000 level or higher.

<sup>5</sup> Can be taken either semester senior year.

## Concentrations

### ***Radiation Applications***

This area of concentration is intended for students who wish to develop expertise in various industrial and other applications of radiation, including radiation damage or enhancement of materials, nondestructive testing, etc.

### ***Radiation Effects on Electronics***

This area of concentration is intended for students interested in using radiation techniques to create advanced solid-state electronic circuitry and/or those interested in understanding how optical/electronic devices respond to radiation.

### ***Multiphase Science and Technology***

This area of concentration is concerned with applications of fluid mechanics and heat transfer technology to the interactions between mixtures of gases, liquids, and solids.

### ***Fusion Applications***

This area of concentration deals with the development and engineering applications of plasmas and the analysis of advanced magnetic confinement and laser-driven fusion power systems.

## Humanities or Social Sciences Electives

In this area, the electives are based on the Institute and School of Engineering requirements. Students are urged to elect humanities and social science sequences through which they will obtain adequate breadth and depth in subject areas. Students desiring minors in Humanities and Social Sciences must consult the school or department in which the courses are offered to obtain further information and specific requirements.

## Dual Major Programs

A dual major program in Engineering Physics and Nuclear Engineering is available to students who follow a prescribed program that can be completed in eight semesters. Further information is available in the departmental office.

## Minor Programs

Students not majoring in engineering physics may receive a minor in this discipline by completing 15–16 credit hours of courses selected in consultation with the program adviser.

## Special Undergraduate Opportunities

### **Program for Graduates of U.S. Navy Nuclear Power Training School**

Rensselaer's School of Engineering and its Department of Mechanical, Aerospace, and Nuclear Engineering, in cooperation with the Office of Professional and Distance Education and the U.S. Navy, have developed undergraduate degree programs in nuclear engineering and engineering physics for graduates of the U.S. Navy Nuclear Power Training School. Currently, Rensselaer offers programs to personnel stationed at the Kesselring Site in West Milton, New York. These academic programs and resulting degrees are the same as those offered to on-campus students studying this discipline.

Designed to meet the needs of Navy personnel, this program delivers courses and degree programs at a time and place that is convenient to them. Student services are flexible and designed to accommodate the needs of working professionals. Services such as undergraduate admissions and registration are handled entirely by mail, phone, fax, or e-mail. Programs and classes are delivered to Rensselaer's Malta

Commons campus, just 20 minutes from the Kesselring Site. The course schedule developed for the program is coordinated with the shift work schedule of the Navy personnel.

The total number of credit hours required for the B.S. degree in either engineering science or nuclear engineering is 128. The curriculum is comprised of 104 engineering and science credits and four professional development credits. Navy students receive up to 31 credit hours of transfer credits for their Navy Nuclear Power Training School course work, leaving 97 credit hours to be completed at Rensselaer. Courses from other accredited universities may also be considered for transfer. The following is a list of credit transfer courses for graduates of the U.S. Navy Nuclear Power Training School.

Toward a degree in engineering physics:

ENGR-1300	Engineering Processes.....	1 transfer credit
CHEM-1300	Chemistry Principles for Engineers .....	4 transfer credits
USNA-1010	Military and Its Place in Society .....	1 transfer credit
USNA-2040	Naval Ship Systems.....	3 transfer credits
ENGR-2050	Intro. to Eng. Design with Prof. Development I.....	4 transfer credits
ENGR-2940	Engineering Project.....	3 transfer credits
ENGR-2960	Topics in Engineering .....	3 transfer credits
ENGR-4300	Electronic Instrumentation .....	4 transfer credits
MANE-4440	Critical Reactor Laboratory.....	3 transfer credits
ENGR-4010	Professional Development III .....	1 transfer credit

Toward a degree in nuclear engineering, in addition to the courses listed above:

MANE-2400	Fundamentals of Nuclear Engineering.....	4 transfer credits
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The program has been divided into three trimesters (fall, spring, and summer) each calendar year. Students normally take three courses or 12 credit hours per trimester. Each trimester consists of approximately 15 weeks and averages a two-week break between any two consecutive trimesters. The total of 97 credits can usually be completed in two years plus seven to eight months.

Students with prior credits from other academic institutions may be eligible to transfer them to the present program. Rensselaer's designated academic units are responsible for reviewing and approving such transfers. In addition, students may take a validation exam in selected subjects in place of some regular courses. Academic advisers provide advice and assistance in this regard.

Students must be in residence (i.e., enrolled as full-time students with a minimum of 12 credits per semester) for at least four semesters of their curriculum.

The academic director of this program is Michael Z. Podowski, and the program is administered through the Office of Professional and Distance Education.

## Graduate Programs

The department offers graduate programs in mechanical engineering, aeronautical engineering, mechanics, nuclear engineering, and engineering physics. To accommodate a student's career plans and interests, the graduate programs are structured to allow great flexibility in choosing appropriate courses, while ensuring sufficient depth and breadth. The professor assigned to or chosen by a student as the adviser has the knowledge to make suggestions of specific courses to further the student's educational goals.

Among the available degrees are the M.Eng., which is perceived to be more practically oriented and consists of course work; the M.S., which is considered more scholarly or fundamental and must include a thesis; and Ph.D. Listed below are many of the requirements for these degrees. For all degrees,

full-time students must register each semester for the zero credit course MANE- 6900, Graduate Seminar. Complete requirement information is available on the MANE department webpage, <http://www.rpi.edu/dept/mane/deptweb/index.html>

## Master's Programs

### Master of Science

Students work on a research project in conjunction with a professor who serves as the academic adviser. The topic is chosen based on mutual interests and needs. Course work typically focuses on subjects related to the research project. In addition to the Institute requirements and those listed above, the M.S. requires a total of 30 credits, six of which come from the thesis. Of the 24 credits of course work, a minimum of 12 must be at the 6000 level with a minimum of nine of these 6000-level courses from MANE (or courses that are cross-listed with MANE courses), and a minimum of 15 credits overall must be from MANE (or courses that are cross-listed with MANE courses). No more than six credits can be from outside of Engineering or Science.

### Master of Engineering

M.Eng. students will primarily take courses to deepen and broaden their knowledge, usually in a focused area of study. If a project is included in the degree program, the student will have to involve a professor as an adviser. In addition to the Institute requirements and those listed above, the M.Eng. requires a total of 30 credits. If a project is taken, a minimum of 12 credits of coursework must be taken at the 6000 level with a minimum of nine of these taken within MANE (or courses cross-listed with MANE courses). If no project is undertaken, a minimum of 18 credits must be at the 6000 level, with a minimum of 12 of these taken within MANE (or courses that are cross-listed with MANE courses).

Students must also take part in a culminating experience consisting of:

- an approved sequence of three integrated or related courses with at least two courses in MANE, only one of which may be at the 4000 level. One of these courses must involve a project or design experience which integrates or synthesizes knowledge from other courses taken in the master's program, or
- a six-credit project, or
- an internship/practicum involving a minimum of one summer and one semester full-time work in an approved setting.

## Doctoral Programs

For the doctoral degree, 90 credits in addition to the bachelor's or 60 credits in addition to the master's degree are required. Usually, this means that 16 to 20 courses beyond the bachelor's are needed, as specified by the adviser and the doctoral committee, in addition to residence and thesis requirements. Under the guidance of a thesis adviser, the student conducts advanced study and research. If a student chooses to do a thesis with a thesis adviser from another department, a Mechanical, Aerospace, and Nuclear Engineering Department faculty member must be appointed co-chair and the doctoral committee must contain at least two department faculty members. After approximately one year of full-time study, the student should have a research adviser and be advanced to doctoral student status. To attain this milestone a qualifying examination is required. When thesis research has begun and after approximately two years of full-time study, the candidacy examination is taken. At the completion of the research project and after the dissertation has been written, the student must defend the thesis in an open presentation to his or her committee. The degree awarded is the Doctor of Philosophy.

This degree is awarded under the auspices of the Office of Graduate Education when the thesis is directed toward making an original contribution to fundamental knowledge in a particular field or in an interdisciplinary field. A dissertation that is scholarly, creative, original, and publishable may deal also with the relation of a discipline to educational problems and objectives within the field.

## Course Descriptions

Courses directly related to all Mechanical, Aerospace, Nuclear Engineering and Engineering Physics curricula are described in the Course Description section of this catalog under the department code MANE.

## Engineering at Hartford

**Chair:** James C. McKim, Jr. (Interim)

**Associate Chair:** Ernesto Gutierrez-Miravete (Interim)

**Program presently under revision.**

Please access the department website at: <http://www.rh.edu/does/index.html> for revised program.

Rensselaer at Hartford offers an engineering curriculum to accommodate the evolving needs of the engineer. The curriculum helps students establish and build on a solid theoretical base while allowing them to practice their skills. This blend of academic excellence and industrial experience creates a unique learning environment for engineering students at Rensselaer at Hartford. Degree programs are offered in Mechanical Engineering, Electrical Engineering, Computer and Systems Engineering, and Engineering Science together with certificate programs in Quality and Reliability Engineering, Systems Modeling and Analysis, and High Temperature Materials.

## Engineering Degrees

Degrees are awarded in the following fields of engineering:

- M.Eng. in Computer and Systems Engineering
- M.S. in Electrical Engineering
- M.S. in Engineering Science
- M.S. in Mechanical Engineering

Candidates for the master's degree must:

- Prepare a plan of study with their adviser and have it reviewed and approved by the chair of engineering no later than their fourth course
- Complete a plan of study with at least 30 credit hours beyond the bachelor's degree with satisfactory grades. At least 18 of the total major credit hours presented toward the degree must have the suffix numbers 6000–6990 or 7000–7990.
- Complete all requirements within five years of admission.

### Culminating Experience (Engineering Seminar)

The culminating experience is a requirement for the master's degree in Connecticut. It may be fulfilled by any of the following:

- Submitting an engineering seminar paper (0 credit hours) in addition to the required 30 credit hours.
- Completing a six-credit-hour master's thesis along with 24 credit hours of appropriate course work.
- Completing a three-credit-hour master's project along with 27 credit hours of appropriate course work.

### General Engineering Requirements

Students entering the engineering programs are expected to hold a Bachelor of Science degree. Students not holding a degree in one of the traditional engineering disciplines must have at least:

- Mathematics, through Ordinary Differential Equations (three terms or 12 credits)
- Physics (two terms)
- Chemistry and/or Engineering Materials (One term)
- Mechanics (One term)
- Electronics/Circuits (One term)

Students lacking one or more of these courses are expected to take corrective action before entering any of the engineering programs.

The Bachelor of Engineering Technology (BET) degree is not generally considered appropriate preparation for admission to master's degrees and courses in engineering. Applicants with this degree may be required to do significant background repair and/or submit scores from the Graduate Record Examination Engineering test, along with the standard admissions credentials. Application forms for this test may be obtained from the Office of Admissions.

All students entering the engineering programs at Rensselaer at Hartford are expected to be familiar with one of the major higher level programming languages (Fortran, C, Pascal, etc.).

A limited number of elective courses outside a specific engineering discipline may be taken and credited toward an engineering degree. The student's faculty adviser must approve these elective courses.

## Electrical Engineering

### Program presently under revision.

Please access the department website at: <http://www.rh.edu/does/index.html> for revised program.

The Electrical Engineering curriculum is designed for students who wish to focus their study in Digital Communications, Control Systems, and Digital Signal Processing.

A Bachelor of Science degree in Electrical Engineering is the desired background for admission to the program. Other students entering the program should have fulfilled the General Engineering Requirements noted above and the Electrical Engineering Background Requirements listed below.

### Electrical Engineering Background Requirements

- Advanced Mathematics (i.e., Complex Variables, Laplace Transforms, Fourier Analysis, Probability) (One term)
- Digital Logic (One term)
- Electronics/Circuits (active or passive) (One additional term)
- Linear Systems or Feedback Systems (One term)
- Technical Design Elective (e.g., Communications Systems, Semiconductor Devices, Introduction to Microprocessors, Circuit Synthesis) (One term)

Students lacking any of the above courses must consult with their adviser to devise a plan for corrective action.

### Electrical Engineering Program Requirements

The following must be included in a plan of study for the degree of Master of Science in Electrical Engineering:

- At least 18 credit hours in 6000-level courses (or equivalent with approval of adviser)
- At least 21 credit hours in ECSE courses or related technical work
- A three-course specialization to provide depth in an approved technical area
- Engineering Seminar

### Specializations

From the courses currently available at Hartford, a three-course specialization can be constructed in any of the following areas:

- Digital Communications
- Control Systems
- Digital Signal Processing

The student may propose other areas, but they are subject to adviser's approval.

## Computer and Systems Engineering

### Program presently under revision.

Please access the department website at: <http://www.rh.edu/does/index.html> for revised program.

The Master of Engineering in Computer and Systems Engineering provides the student with the appropriate hardware and software tools needed in such critical areas as digital communications and signal processing, robotics and automation systems, computer communication networks, and software engineering.

### Admission Requirements

Students should have received a B.S. degree in Electrical Engineering, Computer Engineering, or Computer Science. Students with a B.S. degree in another engineering discipline, Mathematics or Physics, are subject to the condition that the following essential prerequisites for their chosen area of specialization have been completed:

#### *Digital Communications and Signal Processing*

ECSE-2010	Electrical Circuits
ECSE-2410	Signals and Systems
ECSE-2610	Computer Components and Operations

#### *Computer Communications Networks*

ECSE-2010	Electrical Circuits
ECSE-2410	Signals and Systems
ECSE-2610	Computer Components and Operations

#### *Robotics and Automation Systems*

ECSE-2010	Electrical Circuits
ECSE-2410	Signals and Systems
ECSE-2610	Computer Components and Operations

#### *Software Engineering*

CSCI-1100	Computer Science I
CSCI-2300	Data Structures and Algorithms
ECSE-2610	Computer Components and Operations

### Computer and Systems Engineering Program Requirements

The following must be included in a plan of study for the degree of Master of Engineering in Computer and Systems Engineering:

- At least 18 credit hours in 6000-level courses (or equivalent with approval of adviser)
- At least 21 credit hours in ECSE courses or related technical work
- A three-course specialization to provide depth in an approved technical area
- Engineering Seminar

#### Specializations

From the courses currently available at Hartford, a three-course specialization can be constructed in any of the following areas.

- Digital Communications and Signal Processing
- Computer Communication Networks
- Robotics and Automation Systems
- Software Engineering

The student may propose other areas, but they are subject to adviser's approval.

Preparatory courses do not apply toward the minimum 30 credit hours required for the Master of Engineering degree.

## Engineering Science

The Engineering Science curriculum serves students whose educational needs do not correspond to the standard professional engineering curricula. It allows students to tailor courses of study to their particular requirements. Each student's course of study is developed in consultation with the Chair to allow a strongly directed interdisciplinary approach.

The degree awarded in this area is not, nor is it intended to be, accredited for practice. Students entering the Engineering Science program are expected to have fulfilled the General Engineering Requirements noted above.

## Mechanical Engineering

### Program presently under revision.

Please access the department website at: <http://www.rh.edu/does/index.html> for revised program.

The Master of Science in Mechanical Engineering allows the student to increase his or her competence in a number of mechanical engineering subjects, or to specialize in depth in the areas of fluid mechanics, heat transfer, mechanical design, solid mechanics, or thermodynamics.

A Bachelor of Science degree in Mechanical Engineering is the desired background for admission to the program. Other students entering the program should have fulfilled the General Engineering Requirements noted above, and the Mechanical Engineering Background Requirements listed below.

### Mechanical Engineering Background Requirements

- Chemistry (One additional term)
- Statics (One term)

- Dynamics (One term)
- Strength of Materials (One term)
- Fluid Mechanics (One term)
- Heat Transfer (One term)
- Mechanisms (One term)
- Machine Design (One term)
- Thermodynamics (Two terms)

Students lacking any of the above courses must consult with their adviser to devise plans for corrective action.

### **Mechanical Engineering Program Requirements**

A plan of study must include the following items.

- MEAE-4960      Numerical Analysis for Engineers
- MEAE-7010      Math of Engineering and Sciences

(These courses may be waived if the student is competent in the subject.)

- At least 18 credit hours in mechanical engineering courses at an advanced level (or equivalent with approval of adviser). All courses with the suffix numbers 6000–6990 and 7000–7900 apply.
- At least 21 credit hours in MEAE courses
- A minimum of 30 credit hours, including Engineering Seminar. A limited number of elective courses outside the area of mechanical engineering are permitted. However, the student's adviser must approve these courses.

### **Graduate Certificate in High Temperature Materials**

Materials used in the “hot zones” of propulsion and power generation systems must satisfy stringent demands for integrity and performance. Materials exposed to these extreme environments exhibit continuously evolving microstructures, and this must be accounted for during the component design stage of production.

Rensselaer offers a Certificate of Advanced Graduate Studies in High Temperature Materials designed to provide an understanding of the properties of high temperature alloys as well as skills in improving those properties by manipulating the material microstructure through processing.

The Certificate of Advanced Graduate Studies in High Temperature Materials Technology in Propulsion and Power Generation is awarded on successful completion of three graduate level courses. Academic credit from these courses can then be applied towards a Master of Science degree.

### **Professional Engineering**

Professional Engineering seminar topics and preparatory programs for the Professional Engineering Exams are provided in our Engineering course schedules and Web site. The exam review courses for Part I (EIT) and II (PE) and Land Surveyor are held evenings for 10 to 12 weeks prior to the April and October state exams. Rensselaer at Hartford works closely with the State of Connecticut to provide testing schedule information as well as application requirements.

- Fundamentals of Engineering (EIT) Review Course
- Professional Engineering Review Courses (Mechanical, Electrical, and Civil)
- Land Surveyor Review Course

## Interdisciplinary Programs and Research

Rensselaer has long understood that neither student career interests nor modern industry needs are easily pigeonholed into a single discipline. In fact, the discovery of new and more advanced technologies more often than not results from combining the knowledge of a variety of disciplines. Rensselaer is, therefore, resolved to become a leader in providing numerous opportunities for interdisciplinary study.

In keeping with this commitment, the School of Engineering has developed a variety of special programs that bridge one or more departments or even Institute schools. These include both degree and research programs that allow students to develop a breadth and depth of knowledge in more than one discipline. By their nature, these programs are highly flexible and often involve working in teams with faculty and students representing multiple disciplines.

In addition to opportunities in the School of Engineering described below, other interdisciplinary programs available at Rensselaer are listed in the Interdisciplinary Studies Index of this catalog and are described fully in the section pertaining to the associated Institute school or division.

### Engineering Science

**Chair:** Kevin C. Craig

Rensselaer's engineering science curriculum serves students whose educational desires do not correspond to the standard professional engineering curricula. While no B.S. degree is offered in engineering science, M.S. and Ph.D. degrees are awarded to students whose programs of study are *truly* multidisciplinary. However, since each student develops an individual program in consultation with a faculty adviser, the program provides the opportunity to tailor programs of study to specific needs.

Studies may be based on the sciences. For example, programs may concentrate on the application of engineering and scientific techniques to areas between technology and the humanities and social sciences.

Students may also develop a program providing a liberal education based on engineering and involving a critical appreciation of the increasingly technical culture. Such courses of study may form the basis for premedical, prelaw, or prebusiness programs.

#### Faculty

D. Kaminski, G.A. Gabriele, W.C. Jennings, B.K. Malaviya, J.M. Tien, H.F. Tiersten, W.A. Wallace

### Flexible Manufacturing Center

**Co-Directors:** Stephen J. Derby, Raymond H. Puffer, Jr.

**FMC Home Page:** <http://www.fmc.rpi.edu>

The mission of the Flexible Manufacturing Center (FMC) is to conduct research and education related to modular, flexible manufacturing systems and processes. An increasingly competitive global environment has led to ever shorter product life cycles. Flexible manufacturing systems and processes are necessary to cost effectively produce under these conditions. Flexibility during process operation accommodates a broad product mix, while flexibility in overall system design will accommodate product and process reconfiguration and redeployment. The FMC has also been involved with many projects dealing with materials that are themselves flexible.

The objectives of the FMC are to: develop solutions for manufacturing research problems using a team of interdisciplinary scientists and engineers; provide both graduate and undergraduate students with a unique educational opportunity to conduct R&D and gain experience solving industrially relevant problems and

prepare them to “hit the ground running” in key technical positions in industry; advance state-of-the-art in flexible, energy efficient & environmentally friendly manufacturing processes; develop underpinning technologies required to support manufacturing a flexible product mix with short cycle times; serve as a model for industry/university/government partnership to solve societal problems; and build long-term relationships with clients of all sizes to become their “manufacturing and process R&D lab.”

Current research projects include; manufacturing processes and systems for high temperature proton exchange membrane fuel cell components; automation of pattern assembly for investment casting; automated handling of contact lenses during manufacture and inspection; vision based inspection of contact lenses; material handling of limp and viscous materials; laser processing of flexible materials; and peak load management systems development. FMC researchers have also conducted numerous short term projects for manufacturers in collaboration with the NASA Space Technology Outreach Program (SATOP).

**Affiliated Faculty/Staff:**

K. Anderson, B. Benicewicz, S. Chiappone, K. Craig, S. Derby, M. Jensen, R. Puffer, S. Rock, L. Ruff, M. Steiner, J. Tichy, D. Walczyk

## Product Design and Innovation

This dual major program, which the Schools of Engineering and Humanities and Social Sciences offer jointly, satisfies the requirements for the Bachelor of Science programs in both Mechanical Engineering and Science, Technology, and Society (STS). Product Design and Innovation (PDI) prepares students to become innovative designers who will develop and design the advanced products and technologies needed in the future. Built around a design studio every semester, PDI combines the technical sophistication of Rensselaer’s engineering curriculum with the insight and vision of the humanities and social science disciplines in the STS curriculum.

The design studio that students take every semester is the PDI core, which gives them a hands-on opportunity to bring together the two major curricula. The engineering curriculum provides a fundamental education in engineering science through basic courses in engineering mechanics, engineering electronics, energy, materials, and manufacturing. The STS curriculum provides a fundamental education in the economic, ethical, cultural, and political dimensions of product development and innovation, including numerous case studies of successes and failures that help students learn what it takes to be effective leaders of design teams. Through the design studios, students explore and develop their creativity while building a portfolio of design experiences continuously throughout all four years.

The design experiences range from larger systemic problems to smaller focused problems, so that students have broad exposure to different applications of design practice. Some fall and spring semester studios are taught as a sequence to give students experience with the design process from beginning to implementation. The studios also develop students’ skills in using computers and other advanced tools and techniques, as well as in drawing, visualizing, communicating, and working together.

PDI graduates are thus uniquely prepared to put their creativity to work as leaders of design and innovation, whether in a multinational business at the cutting-edge of the global market or in a smaller business that creates an unusual solution to a local problem. They are able to function effectively in the new situations and unfamiliar environments of a multicultural global society, to collaborate with diverse constituencies to analyze and formulate problems of varying complexities, and to work individually and in teams to develop truly innovative and powerful solutions to challenges affecting this country’s continued prosperity and social well-being. Programs corresponding to PDI are described in the School of Architecture and the Humanities and Social Sciences STS Department sections of this catalog.

**Product Design and Innovation Curriculum****First Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
ARCH-2200	Design Studio I	4	ENGR-2020	PDI Studio II <sup>2</sup>	4
STSH-1110	Introduction to STS (First-Year Studies)	4	ENGR-1100	Introduction to Engineering Analysis	4
MATH-1011	Calculus I	4	MATH-1020	Calculus II	4
ENGR-1500	Chemistry of Materials I	4	ENGR-1300	Engineering Processes <sup>1</sup>	1
ENGR-1200	Engineering Graphics and CAD <sup>1</sup>	1	STSS-2960	Design Culture and Society	4
		17			17

**Second Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
IHSS-2500	Design Studio III <sup>3</sup>	4	ENGR-2050	Intro to Engineering Design	4
ENGR-1600	Materials Science for Engineers	4	ENGR-2530	Strength of Materials	4
MATH-2400	Introduction to Differential Equations	4	ENGR-2090	Engineering Dynamics	4
PHYS-1100	Physics I for Engineers	4	PHYS-1200	Physics II for Engineers	4
CSCI-1190	Programming	1			16
		17			16

**Third Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
ARCH-4960	Design Studio V <sup>4</sup>	4	ENGR-4960	Design Studio VI	4
STSS-4xxx	STS Advanced Option <sup>5</sup>	4	STSS-4xxx	STS Advanced Option <sup>5</sup>	4
ENGR-2710	General Manufacturing Processes	3	ENGR-4050	Modeling and Control	4
ENGR-2350	Embedded Control	4	ENGR-2550	Thermo/Fluids Engineering I	4
ENGR-2600	Modeling and Analysis of Uncertainty	3			16
		18			16

**Fourth Year**

<b>Fall</b>		<b>Credit hours</b>	<b>Spring</b>		<b>Credit hours</b>
MANE-4260	Design of Mechanical Systems	3	MANE-4980	PDI Capstone Project	4
MANE-4030	Elements of Mechanical Design	4	ENGR-4300	Electronic Instrumentation	4
MANE-4040	Mechanical Systems Lab	2	MANE-4010	Thermo Fluids Engr. II	4
MANE-4908	STS Senior Project <sup>7</sup>	4	MANE-4020	Thermo Fluids II Lab	2
STSS-4800	Public Service Internship <sup>6</sup>	4	ENGR-4010	Professional Development III	1
		17			15

<sup>1</sup> These courses may be taken in any order.<sup>2</sup> PDI II, V, VI, and GMP satisfy the mechanical engineering requirement for the concentration electives in Product Design and Innovation.<sup>3</sup> For PDI students, IHSS-2500 can be used as a substitute for the second-year requirement in the STS area option.<sup>4</sup> PDI II, V, VI, and GMP satisfy the mechanical engineering requirement for the concentration electives in Product Design and Innovation.<sup>5</sup> Candidate courses include STSS-4350; STSS-4960; STSS-4960; STSH-4230; STSS-4110; STSS-4250; STSS-4310; STSS-4560; and STSS-4650.<sup>6</sup> This course satisfies the requirement for Professional Development II.<sup>7</sup> The STS Senior Project can be combined with the PDI Capstone Design Studio to make an 8-credit capstone studio project. Coordination should be done with your PDI adviser.

## Center for Image Processing Research

**Director:** William A. Pearlman

**Associate Director:** John W. Woods

**CIPR Home Page:** <http://www.cipr.rpi.edu>

The Center for Image Processing Research (CIPR) conducts a range of research and academic programs in image and video processing. Faculty participants represent a number of academic disciplines and, together with their students, provide the nucleus for ongoing activities within CIPR. In addition to providing an intellectual focus for image-processing activities at Rensselaer, the objectives are to provide a positive impact on graduate and undergraduate programs, to support ongoing activities with a world-class infrastructure, and to enhance its reputation as one of the world's premier image-processing research centers. Current CIPR research areas include image modeling, computer vision and image analysis, document analysis and processing, image and video enhancement and reconstruction, biomedical image processing, computer graphics, computational geometry, image and video compression and transmission, virtual video synthesis, visualization and display techniques, and multimedia systems. The CIPR has administrative authority over and shares infrastructure with the NSF Industry/University Center for Next Generation Video (CNGV) and the NSF Engineering Research Center for Subsurface Sensing and Imaging System (CenSSIS) at Rensselaer. These centers have some joint research programs with CIPR, but otherwise operate independently of CIPR.

### Affiliated Faculty

C. Carothers, R.W. Franklin, L. Gerhardt, S. Kalyanaraman, G. Nagy, W.A. Pearlman, R. Radke, K. Rajan, B. Roysam, K.S. Vastola, J.W. Woods, X.-C. Zhang

## Center for Infrastructure and Transportation Studies

**Director:** George F. List

**Director of Research:** William A. Wallace

**Senior Research Associate:** Donald N. Geoffroy

**CITS Home Page:** <http://www.rpi.edu/dept/cits>

The Center for Infrastructure and Transportation Studies (CITS) provides a focal point for campus research addressing the world's infrastructure and transportation needs. CITS also assists in coordinating all related pedagogical initiatives. About 15 faculty across the Institute participate.

The Center's research program focuses on five themes: intelligent transportation systems, information technology, deployment, and application, network analysis and control, asset management, and advanced materials. Each aspect of the life cycle for infrastructure and transportation systems is of interest—planning, analysis, design, maintenance, operation, preservation, restoration, and renewal. Common infrastructure focal points are roadways, bridges, and power distribution networks.

Projects currently under way include wireless ATIS systems, incident management systems, critical infrastructure interdependencies, investment planning for multimodal freight networks, capacity analyses for highway facilities, multilayer network modeling, and advanced concrete technologies. The pedagogical activities include course material development in the areas of intelligent transportation systems and asset management.

**Affiliated Faculty**

A. Balfour, D. Berg, F. Bronet, J. Chow, K. Connor, A. Desrochers, R. Dobry, G. Dvorak, M. Embrechts, L. Feeser, J. Fish, J. Haddock, C. Hsu, M. Kalsher, G. List, H. Littman, C. Malmberg, R. Messler, D. Millard, L. Myrabo, G. Nagy, K. Nelson, M. O'Rourke, J. Plawsky, M. Raghavachari, S. Salon, G. Saulnier, M. Shephard, G. Simons, P. Sullo, J. Tien, D. Vitaliano, W. Wallace

**Center for Multiphase Research**

**Director:** Michael Z. Podowski

**CMR Home Page:** <http://www.ne.rpi.edu/cmr>

In this country, Rensselaer's interdisciplinary Center for Multiphase Research (CMR) is the premier research center of its kind. The CMR has assembled a large and dynamic group of scientists and engineers dedicated to exploring and exploiting new developments in every conceivable aspect of multiphase flow and heat transfer technology. The CMR coordinates the diverse activities of these researchers and facilitates the cross-disciplinary exchange of information as well as technology transfer to industry.

Multiphase flow occurs in any physical process or industrial system involving more than one phase (solids, liquids, and vapors). Multiphase flow and related heat transfer technology are the keys to increasing the productivity and efficiency of many American industries. Indeed, this technology underlies our understanding of crystal growth, foundry casting, high-power density electronic cooling, chemical processing, petroleum refining, and slurry and pneumatic transport. Multiphase technology also has basic applications to aircraft wing icing, deep-sea mining, aseptic food processing, pharmaceutical manufacturing, refrigeration and air conditioning, chemical and nuclear reactor safety, foam production, aerosols, particulate erosion, combustion, processing and propulsion in outer space, enhanced petroleum recovery and bioreactors. Moreover, there are many important defense applications for this technology.

Historically, multiphase flows have been analyzed empirically. As a result, these analyses necessarily included many uncertainties and inaccuracies. Thus, the design and operation of phase change equipment had to include large margins. Recent developments in supercomputing, symbolic manipulator algorithms, diagnostic instrumentation, and applied mathematics have driven revolutionary changes in scientists' ability to understand and predict multiphase flow phenomena.

The research activities of the CMR involve faculty, staff, and graduate students of many backgrounds who work synergistically on relevant multiphase research. Some typical research projects are:

- Conducting crystal growth experiments in outer space.
- Developing state-of-the-art laser optical diagnostic system for measuring multidimensional phenomena.
- Developing CFD models of multiphase flows.
- Predicting critical heat flux (CHF) using first principle models.
- Understanding instability phenomena in various phase change systems.
- Investigating laser materials processing, thin film behavior, and ultrahigh boiling heat fluxes.
- Imaging interfacial structures in gas/liquid flows.
- Assessing the consequences of hypothetical nuclear reactor accidents.

The members of the center represent a broad spectrum of science and engineering disciplines and have access to a wide variety of equipment and computational power.

**Affiliated Faculty**

S. Antal, G. Belfort, A.E. Bergles, D. Drew, J.E. Flaherty, W. Gill, M. Glicksman, A. Hirsra, K. Jansen, M. Jensen, D. Kaminski, R.T. Lahey Jr., H. Littman, R.I. Nigmatulin, A. Ostrogorsky, M.Z. Podowski, M.S. Shephard, R. Smith, D. Sperber, B. Szymanski, P. Wayner

**Center for Next Generation Video**

**Director:** John W. Woods

**CNGV Home Page:** <http://www.ecse.rpi.edu/CNGV>

The Center for Next Generation Video (CNGV) is an NSF Industry-University Cooperative Research Center dedicated to advancement of the state-of-the-art in compression, transmission, reception, processing, and networking of digital video and multimedia. The Center is operated in partnership with the New Jersey Institute of Technology, with Rensselaer as its headquarters.

**Center for Subsurface Sensing and Imaging Systems**

**Director:** Badrinath Roysam

**CenSSIS Home Page:** <http://www.ecse.rpi.edu/censsis>

The Center for Subsurface Sensing and Imaging Systems (CenSSIS) is a National Science Foundation Engineering Research Center (NSF-ERC) that conducts multidisciplinary research on common solutions to diverse problems for sensing and imaging objects that are hidden under a surface. This is part of a larger center involving Northeastern University, Boston University, University of Puerto Rico at Mayagüez, and several affiliate institutions including The Woods Hole Oceanographic Institute, Memorial Sloan-Kettering Cancer Center, Massachusetts General Hospital, Idaho National Engineering and Environmental Laboratory, and Lawrence Livermore National Laboratory. Examples of applications include deep confocal laser-scanning microscopy of minute subcellular objects, electrical impedance tomography of the human body and underground waste sites, retinal imaging, surgical planning for radiation treatment, and inspection of hidden defects in roads and bridges. These diverse applications are addressed using advanced computer algorithms for tomographic image reconstruction, image analysis, and computer vision. Some projects involve design and fabrication of working prototypes using advanced electronics, processors, and embedded algorithms. Graduate and undergraduate students participate on various projects at the center. Opportunities also exist for qualified K-12 students to participate in selected projects.

**Affiliated Faculty**

K. Bennett, C. Carothers, M. Cheney, D. Isaacson, J. Newell, R. Radke, B. Roysam, G. Saulnier, C. Stewart, B. Yazici, X.-C. Zhang