Case School of Engineering

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Engineering seeks to create new processes, products, methods, materials, or systems that impact and are beneficial to our society. To enable its graduates to lead the advancement of technology, The Case School of Engineering (CSE) offers fourteen degree programs at the undergraduate level (thirteen engineering degrees plus the B.S. in computer science). At the post-graduate level, the CSE offers Master of Science programs and the Doctor of Philosophy for advanced, research-based study in engineering. CSE also offers two specialized degrees at the Master's level: a Master of Engineering specifically for practicing engineers, and an integrated Master of Engineering and Management jointly administered with the Weatherhead School of Management. The faculty and students participate in a variety of research activities offered through the departments and the interdisciplinary research centers of the University.

At the core of its vision, The Case School of Engineering seeks to set the standards for excellence, innovation, and distinction in engineering education and research prominence.

Statement of Educational Philosophy

The Case School of Engineering prepares and challenges its students to take positions of leadership in the professions of engineering and computer science. Recognizing the increasing role of technology in virtually every facet of our society, it is vital that engineering students have access to progressive and cutting-edge programs stressing five areas of excellence

- Mastery of fundamentals
- Creativity
- Societal awareness
- Leadership skills, and
- Professionalism

Emphasizing these core values helps ensure that tomorrow's graduates are valued and contributing members of our global society and that they will carry out the tradition of engineering leadership established by our alumni.

The undergraduate program aims to create life-long learners by emphasizing engineering fundamentals based on mathematics, physical and natural sciences. Curricular programs are infused with engineering creativity, professionalism (including engineering ethics and the role of engineering in society), professional communications, and multi-disciplinary experiences to encourage and develop leadership skills. To encourage societal awareness, students are exposed to and have the opportunity for in-depth study in the humanities, social sciences, and business aspects of engineering. Undergraduate students are encouraged to develop as professionals. Opportunities include the Cooperative Education Program, on-campus research activities, and participation in the student chapters of professional societies. Graduates are prepared to enter the workforce and be strong contributors as practicing engineers, or continue for advanced study in engineering.

At the graduate level, The Case School of Engineering combines advanced classroom study with a rigorous independent research experience leading to significant results appropriate for publication in archival journals and/or presentation at leading technical conferences. Scientific integrity, engineering ethics, and communication skills are emphasized throughout the program.

Brief History

The Case School of Engineering was established on July 1, 1992, by an action of the Board of Trustees of Case Western Reserve University as a professional school dedicated to serving society and meeting the needs of industry, government and academia through programs of teaching and research.

The Case School of Engineering continues the tradition of rigorous programs based on fundamental principles of mathematics, science and engineering that have been the hallmark of its two predecessors, the Case School of Applied Science (Founded in 1880) and the Case Institute of Technology (1947). The formation of The Case School of Engineering (CSE) is a re-commitment to the obligations of the gift of Leonard Case, Jr., to serve the citizens of Northern Ohio. The CSE has been a leader in many educational programs, being the first engineering school to offer undergraduate programs in computer engineering, biomedical engineering, polymer engineering and systems and control engineering.

Administration

Robert F. Savinell, Ph.D. (University of Pittsburgh)
Dean of The Case School of Engineering and George S. Dively Professor of Engineering

James D. Cawley, Ph.D. (Case Western Reserve University)
Associate Dean of Undergraduate Programs

Joseph M. Mansour, Ph.D. (Rensselaer Polytechnic Institute)
Associate Dean of Research and Graduate Programs

Christine A. Ash, M.B.A. (Case Western Reserve University)
Associate Dean of Administration and Finance

Deborah J. Fatica, M.A. (Bowling Green State University)
Assistant Dean of Curricular Enhancements and External Assessments

Leslie A. Sabo (Bowling Green State University/Candidate for M.B.A./WSOM)
Assistant Dean of Development and External Affairs

Engineering Degrees Granted

1. Bachelor of Science in Engineering degree with major designations as follows
   - Aerospace engineering
   - Biomedical engineering
   - Chemical engineering
   - Civil engineering
   - Computer engineering
   - Electrical engineering
   - Engineering physics
   - Fluid and thermal engineering science
   - Mechanical engineering
   - Materials science and engineering
   - Polymer science and engineering
   - Systems and control engineering
2. Bachelor of Science in Engineering without designation, for programs that emphasize interdisciplinary areas or for programs that include some emphasis on non-technical fields.
3. Bachelor of Science in Computer Science
4. Master of Engineering (practice-oriented program)
5. Master of Engineering and Management
6. Master of Science with the following major field designations
   - Aerospace engineering
   - Biomedical engineering
   - Ceramics and materials science
   - Chemical engineering

Civil engineering
Computer engineering
Computing and information science
Electrical engineering
Engineering mechanics
Fluid and thermal engineering
Macromolecular science
Materials science and engineering
Mechanical engineering
Systems and Control Engineering

7. Master of Science without designation.
8. The Doctor of Philosophy without designation (for all programs).

Undergraduate Degree Programs

In addition to the major department requirements, each engineering undergraduate degree program includes the Engineering Core, which provides a foundation in mathematics and sciences as well as aspects of engineering fundamentals for programs in engineering. The Engineering Core also is designed to develop communication skills and to provide a body of work in the humanities and social sciences. Requirements of the Engineering Core can be found elsewhere in this bulletin.

Details of the specific curricular requirements for the undergraduate majors are described in the respective departmental descriptions.

Advanced Degree Programs

Master of Engineering Program

The practice-oriented Master of Engineering Program targets currently employed engineers. The objective of this program is to provide engineers in industry with technical as well as business, management, and teamwork skills. The program differs from a traditional Master of Science degree in engineering by concentrating on current industrial practice rather than on research.

The Master of Engineering Program prepares students to enhance their role as corporate leaders. The program provides an environment in which practicing engineering professionals can address the increasingly wide range of technical, management, financial and interpersonal skills demanded by an ever-expanding and diverse global industry base.

Participants can complete a master's degree within a two-year (six semester), part-time, program of study. The Master of Engineering program requires 30 credit hours of course work which includes 18 credit hours of core courses and 12 credit hours of technical electives chosen from a focus area. Core courses aim at equipping participants with knowledge on how engineering is practiced in contemporary industry. Technical elective courses provide depth in a chosen specialty area. All courses are held in the late afternoon or evening hours and many are provided in a distance–learning format to minimize disruption at the workplace and home. Because the program makes extensive use of computers, participants need to have access to computer facilities.

The Program

The program consists of a set of six core courses and a four course technical elective sequence (a total of 30 credit hours are required). The core courses provide a common base of study and experience with problems, issues, and challenges in the engineering business environment. The technical course sequence provides an opportunity to update disciplinary engineering skills and to broaden interdisciplinary skills. An in-residence retreat is required of all students on the weekend prior to the summer semester. Up to six transfer credits may be approved for graduate-level courses taken at Case Western Reserve or another accredited university.

Six Core Courses

- Team Leadership, Presentation Skills and Professional Assessment and Development (EPOM 400 A,B & C)
- Applied Engineering Statistics (EPOM 405)
- Engineering Economics/Financial Analysis (EPOM 407)
- Business for Engineers (MGMT 421)
- Product/Process Design and Implementation (EPOM 403)
- Master of Engineering Capstone Project (EPOM 409)

Four Technical Electives

Four courses from the chosen technical concentration area are required. The following technical concentration areas are offered:

- Automation, Manufacturing, and Control Systems
- Chemical and Material Processing and Synthesis
- Computer Engineering
- Mechanical Engineering

Master of Engineering and Management Program

The Master of Engineering and Management program is designed to meet the needs of students seeking to excel in engineering careers in industry. The MEM degree requires only one calendar year of additional study and may be entered following a student's Junior or Senior year. The Program prepares engineers to work in different business environments. A rigorous curriculum prepares graduates to build synergy between the technical possibilities of engineering and the profit-loss responsibilities of management. This Program evolved after years of research and interviews with over 110 professionals and 28 corporations in the U.S.

The Program

The program includes 42 credit hours of graded course work. The ten-course core sequence makes up 30 of these hours. Students choose an area of concentration, either technology entrepreneurship or biomedical entrepreneurship, for the remaining 12 credits. The Program prepares participants to function as technical leaders with a unique blend of broadened engineering and management skills, which can have a strategic impact on the organization's bottom line. Graduates are uniquely positioned for rapid advancement in technology-based organizations.

Ten Core Courses

- Professional Development (IIME 400)
- Project Management (IIME 405)
- Accounting, Finance, and Engineering Economics (IIME 410)
- Materials and Manufacturing Processes (IIME 415)
- Product and Process Design, Development and Delivery I & II (IIME 430 A & B)
- Information Technology & Systems (IIME 420)
- Understanding People and Change in Organizations (IIME 425)
- Engineering Entrepreneurship I & II (IIME 450 A & B)

Technology Entrepreneurship Concentration

- Design for Manufacturing and Manufacturing Management I & II
- Engineering Statistics and Quality I & II

Biomedical Entrepreneurship Concentration

- Engineering Statistics for Biomedical Applications
- Models for Health Care and Regulatory Affairs

Two courses from the following areas

- Biomedical Imaging: EBME 410, EBME 431, EBME 400, EBME 461
- Biomaterials/Tissue Engineering: EBME 403, EBME 406, EBME 408, EBME 416
- Neuroprostheses: EBME 407, EBME 507, EBME 417
- Cardiac Bioelectricity: EBME 417, EBME 501, EBME 502
- Biomedical Instrumentation and Sensors: EBME 403, EBME 414, EBME 418

Master of Science Degree Programs

Recognizing the different needs and objectives of resident and non-resident graduate students pursuing the master's degree, two different plans are offered. In both plans, transfer of credit from another university is limited to six hours of graduate-level courses, taken in excess of the requirements for an undergraduate degree, approved by the student's advisor, the department chair, and the Dean of the School of Graduate Studies.

All Master of Science degree programs require the submission of a program of study which must be approved by the advisor, department chairperson and the dean of engineering and which must be submitted before registering for the last 9 course credits of the program.

Plan A - Thesis

Minimum requirements for the degree of Master of Science in a major field under this plan are

1. Completion of 18 hours of graduate course work. The courses must be approved by the department offering the degree, as well as the dean of engineering.
2. Completion of nine hours of thesis work culminating in a thesis examination given by at least three professors, plus approval by the chair of the department offering the degree. A student with research experience equivalent to a thesis may petition the Graduate Committee of The Case School of Engineering for substitution of nine hours of course work for the thesis requirement. In this case, the thesis examination above is replaced by a similar examination covering the submitted research work and publications.

At least 18 hours of total course work, including up to 9 hours of thesis research, must be at the 400 level or higher.

Plan B - Engineering Project

Minimum requirements for the degree of Master of Science in a major field under this plan are

1. Completion of 27 hours of graduate course work including a Special Problems course described in item 2. The program must be approved by the department offering the degree, as well as the dean of engineering.
2. Three to six hours of Special Problems course work, which must consist of an engineering project approved by the chair of the department offering the degree, which may be carried out at the student's place of employment with nominal supervision by a faculty advisor or in the division laboratories under direct supervision. The project must culminate in a written report and examination by at least three professors plus approval by the chair of the department offering the degree. The Special Problems course may be waived for students who have had industrial design or research experience and who submit sufficient evidence of this experience in the form of a publication or internal report. For these students, a minimum of 27 hours of course work and the final oral examination covering the submitted publications or reports as well as related course material will be required for the master's degree. At least 18 hours of course work including up to 6 hours of Special Problems must be at the 400 level or higher.

Undesignated Master of Science Degree

A student working toward an undesignated Master of Science degree in engineering must select a department. The student is responsible for submitting a program of study which must have the approval of the student's advisor and department head and the dean of engineering and which must contain a minimum of nine semester hours of course work in the department approving the program. A minimum of 18 semester hours of course work for the degree must be at the 400 level or higher. The student must meet all the requirements of the designated Master of Science degree in engineering.

Doctor of Philosophy Degree

The student's Ph.D. program should be designed to prepare him or her for a lifetime of creative activity in research and in professional engineering practice. This may be coupled with a teaching career. The mastery of a significant field of knowledge required to accomplish this purpose is demonstrated by an original contribution to knowledge embodied in a thesis and by satisfactory completion of a comprehensive course program which is intensive in a specific area of study and includes work in other areas related to, but not identical with, the major field. The necessity for breadth as well as depth in the student's education cannot be overemphasized. To this end, any engineering department may add additional requirements or constraints to ensure depth and breadth appropriate to its field.

No student may be admitted to candidacy for the Ph.D. degree before approval of his or her program of study by the Advisory Committee, the department, and the dean of engineering. After this approval has been obtained, it is the responsibility of the student's department to notify the Dean of the School of Graduate Studies of his or her admission to candidacy after the student has fulfilled any additional department requirements. Minimal requirements in addition to the university requirements are

1. The minimum course requirement beyond the B.S. level is 36 credit hours of courses taken for credit, at least 18 hours of which must be taken at Case Western Reserve University. The following courses taken for credit will be acceptable for a Ph.D. program of study
   a. All 400-, 500-, and 600-level courses,
   b. Those 300-level courses approved by the student's department up to a maximum of three beyond the B.S. or a maximum of one beyond the M.S., and
   c. Approved graduate-level courses taken at other institutions
2. A minimum depth in basic science equivalent to six semester hours (for credit) is required. This requirement is to be satisfied by courses that have been previously approved by the faculty of the department in which the student is enrolled.
3. The requirement for breadth is normally satisfied by a minimum of 12 semester hours of courses (for credit) outside the student's major area of concentration as defined by the student's department and does not include courses taken to fulfill the basic science requirement.
4. A minimum of three teaching experiences as defined by the student's department. All programs of study must include departmental 400T, 500T, and 600T courses to reflect this requirement.
5. The minimum requirement for research is satisfied by at least eighteen hours of thesis (701) credits.
6. A cumulative quality-point average of 3.0 or above in all courses taken for credit as a graduate student at Case Western Reserve University (excluding grades in thesis research and grades of R) is required for the award of the doctor's degree.

Qualifying Examination

The student must pass a qualifying examination relevant to his or her area of study as designated by the curricular department with which he or she is affiliated. For students who obtain the M.S. degree from Case Western Reserve University, the qualifying examination should be taken preferably before the end of the student's fourth semester of graduate study but no later than the end of the fifth semester at the University. For students entering with the masters degree the examination should be taken no later than the end of the third semester at the University.

Program of Study

Each student is required to submit a program of study, detailing his or her course work, thesis schedule, and qualifying examination schedule and indicating that all the minimum requirements of the University and the faculty of The Case School of Engineering are satisfied. This program of study must be approved by the advisory committee, the department chairperson and the dean of engineering before registering for the last 18 credits hours of the program.

If the student is pursuing the Ph.D. degree without acquiring the M.S. degree, the program of study should be accompanied by a petition to the dean of engineering to waive the requirement of the M.S. degree. All required courses taken at the University beyond the B.S. degree should be shown on the program of study with the grade if completed. If the requirements are to be fulfilled in other than the standard ways described above, a memorandum requesting approval should be attached to the program of study.

The program of study must be submitted within one semester after passing the qualifying examination.

Undergraduate Courses (ENGR)

ENGR 101. Freshman Engineering Service Project (2)
This course is intended to provide engineering freshman with an initial exposure to engineering problem solving and engineering design in a given technical field or project-driven environment. Small groups of students will be attached to a particular service project, with the assignment of working out and implementing an engineering solution. Collaboration with the Case Engineering Service Group, as well as off-campus service organizations, will provide a source of real world problems, addressing needs within the greater community, for students to work on. Final engineering reports/presentations, as well as actual prototype solutions (possibly either hardware or software), are expected of each group.

ENGR 131. Elementary Computer Programming (3)
An introductory course in algorithmic problem solving. C++ is used to illustrate how the programming concepts can be used to solve engineering and scientific problems.

ENGR 145. Chemistry of Materials (4)
Application of fundamental chemistry principles to materials. Emphasis is on bonding and how this relates to the structure and properties in metals, ceramics, polymers and electronic materials. Application of chemistry principles to develop an understanding of how to synthesize materials. Prereq: CHEM 111 or equivalent.

ENGR 200. Statics and Strength of Materials (3)
An introduction to the analysis, behavior and design of mechanical/structural systems. Course topics include: concepts of equilibrium; geometric properties and distributed forces; stress, strain and mechanical properties of materials; and, linear elastic behavior of elements. Prereq: PHYS 121.

ENGR 210. Introduction to Circuits and Instrumentation (4)
Modeling and circuit analysis of analog and digital circuits. Fundamental concepts in circuit analysis: voltage and current sources, Kirchhoff's Laws, Thevenin and Norton equivalent circuits, inductors capacitors, and transformers. Modeling sensors and amplifiers and measuring DC device characteristics. Characterization and measurement of time dependent waveforms. Transient behavior of circuits. Frequency dependent behavior of devices and amplifiers, frequency measurements. AC power and power measurements. Noise in real electronic systems. Electronic devices as switches. Digital logic circuits. Introduction to computer interfaces. Analog/digital systems for measurement and control. Prereq: MATH 122. Coreq: PHYS 122.

ENGR 225. Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (4)
Elementary thermodynamic concepts: first and second laws, and equilibrium. Basic fluid dynamics, heat transfer, and mass transfer: microscopic and macroscopic perspectives. Prereq: CHEM 111 and ENGR 145 and PHYS 121. Coreq: MATH 223.

Graduate Courses

Master of Engineering Program

EPOM 403. Product and Process Design and Implementation (3)
The course is taught through a series of lectures, class discussions, group projects and case studies. The course aim is to provide a solid understanding of the many aspects of the engineering design process and the management of technology. The course focuses on the engineering and management activities used to develop and bring to market new products and processes. The first part of the course focuses on the techniques used to develop new ideas, the second part focuses on the management of technology and innovation. Prereq: MGMT 421 or permission of instructor.

EPOM 405. Applied Engineering Statistics (3)
In this course a combination of lectures, demonstrations, case studies, and individual and group computer problems provides an intensive introduction to fundamental concepts, applications and the practice of contemporary engineering statistics. Each topic is introduced through realistic sample problems to be solved first by using standard spreadsheet programs and then using more sophisticated software packages. Primary attention is given to teaching the fundamental concepts underlying standard analysis methods.

EPOM 407. Engineering Economics and Financial Analysis (3)
In this course, money and profit as measures of "goodness" in engineering design are studied. Methods for economic analysis of capital investments are developed and the financial evaluation of machinery, manufacturing processes, buildings, R&D, personnel development, and other long-lived investments is emphasized. Optimization methods and decision analysis techniques are examined to identify economically attractive alternatives. Basic concepts of cost accounting are also covered. Topics include: economics criteria for comparing projects: present worth, annual worth analysis; depreciation and taxation; retirement and replacement; effect of inflation and escalation on economic evaluations; case studies; use of optimization methods to evaluate many alternatives; decision analysis; accounting fundamentals: income and balance sheets; cost accounting. Prereq: EPOM 405.

EPOM 409. Mechanical Engineering Capstone Project (3)
This is the capstone course for the Master of Engineering Program providing students with the opportunity to integrate the Program's topics through an intensive case study project. Interdisciplinary teams are assigned a major engineering project that covers the stages from design concept through development to final manufacture, including business and engineering decision making to maximize market penetration. Topics also include safety, environmental issues, ethics, intellectual property, product liability and societal issues. Prereq: MGMT 421, EPOM 403, EPOM 405, and EPOM 407.

Master of Engineering and Management Program

IIME 400. Professional Development (3)
The goal of the course is to help students learn methods for assessing their knowledge, abilities, and values relevant to engineering and management, and for the acquiring of new professional knowledge and skills throughout their career. Prereq: Senior status in engineering.

IIME 405. Project Management (3)
Project Management is concerned with the management and control of a group of interrelated tasks required to be completed in an efficient and timely manner for the successful accomplishment of the objectives of the

project. Since each project is usually unique in terms of task structure, risk characteristics and objectives, the management of projects is significantly different from the management of repetitive processes designed to produce a series of similar products or outputs. Large-scale projects are characterized by a significant commitment of organizational and economic resources coupled with a high degree of uncertainty. Thus, the objective of the course is to understand what are the main issues and problems in the management of projects and to have a thorough knowledge of the conceptual models and techniques available to deal with them. Prereq: Senior status in engineering.

IIME 410. Accounting, Finance, and Engineering Economics (3)
This class uses a combination of class lecture and discussion, in combination with problem-type and case-type assignments, to introduce you to key concepts and tools of financial economics. You are expected to use the resources at your disposal, such as the textbook or the accounting dictionary, to help you understand any unfamiliar concepts. Normally, each class will be divided into two sections. The first part of each class session will be devoted to discussions of selected problems and cases, with focus on the specific topics being covered. The second part of each class will be devoted to prepare you for the following session class assignments. Prereq: Senior status in engineering.

IIME 415. Materials and Manufacturing Processes (3)
A survey course on contemporary and modern materials and their processing, the course begins with a review of traditional materials, including metals, ceramics, plastics, and composites. The evolution of the materials will be traced from their beginnings as raw resources and precursors to finished products. Topics will emphasize modern manufacturing methods and materials. Traditional and modern tools for materials and process characterization will be an important part of the course. Special attention will be directed to examples of statistical methodology and information technology. Visits to local industries and presentations by participating companies will reinforce the information presented in the classroom. Prereq: Senior status in engineering.

IIME 420. Information Technology and Systems (3)
This course is intended to provide students with a perspective of effective use and management of information technology. The primary thrust will be to explain the enabling role of information technology, and how this insight can provide a competitive advantage for industrial organizations in many application areas. In order to accomplish this, technologies such as telecommunications and networking, distributed systems, data management systems, software development, electronic commerce, and the use of multimedia, internet, and web-based systems will be investigated. The impact of these IT technologies for improved industrial productivity and competitiveness. Prereq: Accredited Bachelors in engineering.

IIME 425. People Issues and Change in Organizations (3)
This course is intended to help students assess events occurring in organizations from a behavioral and human resources perspective and to help them develop strategies for managing these events. The course applies knowledge from the fields of organizational behavior and human resource management to provide an understanding and the skills needed to be effective in organizations. The fields of Organizational Behavior and Human Resource Management are devoted to the study of how human beings act in organized settings and how organizations can affect human behavior through a variety of policies, practices, structures, and strategies. In today's environment, organizations are faced with high levels of international competition and an increasing pace of technological, market, and social changes. As an organizational member, you are expected to successfully operate within these increasingly complex demands as well as help create and guide change. The purpose of this course is to provide you with the framework and tools needed to analyze and operate in the changing organization. We will examine some of the features that characterize an emerging organizational form and contrast this to its traditional predecessor. The focus of the course will be on the skills you will need to operate in the "new" organization including skills for being a change agent working in entry level and early career managerial roles. Prereq: Accredited Bachelor's in Engineering plus summer job experience.

IIME 430A. Product and Process Design, Development, and Delivery I (3)
An integrated approach to the teaching of the complex relationship of customer to designer and to manufacturer, this course will be team taught by faculty from WSOM and CSE, with participation of corporate representatives sponsoring projects for the teams. The course will be built on a series of projects, each emphasizing different aspects of the product/process design experience, selected to provide exposure to a wide variety of entrepreneurial activities. The project activities are expected to promote the development of realistic activities of cross-functional teams. Prereq: Accredited Bachelor's in Engineering plus summer job experience.

IIME 430B. Product and Process Design, Development, and Delivery II (3)
An integrated approach to the teaching of the complex relationship of customer to designer and to manufacturer, this course will be team taught by faculty from WSOM and CSE, with participation of corporate representatives sponsoring projects for the teams. The course will be built on a series of projects, each emphasizing different aspects of the product/process design experience, selected to provide exposure to a wide variety of entrepreneurial activities. The project activities are expected to promote the development of realistic activities of cross-functional teams. Prereq: IIME 430A.

IIME 440A. Engineering Statistics and Quality I (3)
This course focuses on process optimization and control using both qualitative and quantitative techniques. At the completion of the course the student should have a thorough understanding of the importance of quality in all organizations, as well as the tools to ensure that the required levels of quality are established and maintained. Prereq: Accredited Bachelors in engineering plus experience.

IIME 440B. Engineering Statistics and Quality II (3)
This course focuses on process optimization and control using both qualitative and quantitative techniques. At the completion of the course the student should have a thorough understanding of the importance of quality in all organizations, as well as the tools to ensure that the required levels of quality are established and maintained. Prereq: IIME 440A.

IIME 450A. Engineering Entrepreneurship I (3)
The nature and importance of entrepreneurship is an area of importance to business leaders, educators, politicians, and individual members of the society. It is a driver of economic development and wealth creation in organization units ranging in size from the individual company to entire nations. Technology-based entrepreneurship is particularly important to this economic development due to its impact on productivity and its potential for exponential growth. To create something new and of value to both the organization and the market requires a technical individual who is willing to assume the social, psychic, and financial risks involved and achieve the resulting rewards whether these be monetary, personal satisfaction, or independence. This can occur while starting an enterprise (i.e., entrepreneurship) or while driving innovation in an existing organization (intrapreneurship). This course will also take students through a variety of issues related to enhancing innovation in the context of a technology-based organization. This is sometimes termed intrapreneurship and includes innovating new products and services within an organization. This is a very complex field and relatively young. Students will learn that there are not many "absolute truths," but there are numerous best practices and benchmarks that can assist the intrapreneur. Prereq: Accredited Bachelors in Engineering plus summer job experience.

IIME 450B. Engineering Entrepreneurship II (3)

Master of Science Degree Programs

Students in all Master of Science degree programs will prepare a program of study in conjunction with their faculty advisor. Complete listings of all gradaute courses appear elsewhere in this bulletin. Graduate students interested in a cooperative educaion experience should register for ENGR 400C while they are on a co-op assignment.

ENGR 400C. Graduate Cooperative Education (0)
An academic opportunity designed for graduate students to enhance their classroom, laboratory, and research learning through participation and experience in various organizational/industrial environments where theory is applied to practice. Graduate Cooperative Education experiences may be integrated with the student's thesis or research project areas, or be solely for the purpose of gaining professional experience related to the student's major field of study. Registration in this course will serve to maintain full-time student status for the period of time that the student is on a co-op assignment.

Interdisciplinary Research Centers

Interdisciplinary research centers act as intensive incubators for students and faculty doing research and studying applications in specialized areas. Thirteen research centers and research programs at The Case School of Engineering have been organized to pursue cutting-edge research in collaboration with industrial and government partners. The transfer of technology to industry is emphasized in all the centers.

The educational programs of these centers encompass the training of graduate students in advanced methods and strategies, thus preparing them to become important contributors to industry after graduation; the involvement of undergraduates in research; the presentation of seminars that are open to interested members of the community; and outreach to public schools to keep teachers abreast of scientific advances and to kindle the interest of students in seeking careers in engineering.

Advanced Liquid Crystalline Optical Materials (ALCOM)

212 Kent Hale Smith Building (7202)
http://www.lci.kent.edu/ALCOM/ALCOM.html
phone 216-368-4176; fax 216-368-4171
Jack L. Koenig, Director
e-mail jlk6@po.cwru.edu

ALCOM, a consortium between Case Western Reserve, Kent State University, University of Akron, and the State of Ohio, conducts research and educational programs in liquid crystal (LC) technology. Thirty-four scientists from diverse fields collaborate to study the properties of LC materials and the application of LC technologies to optical displays. Other uses of LC include high-contrast flat panel displays, optical imaging devices, and thermometers. Future potential applications are flat-panel TV, optical computers, and integrated optical communications.

The center conducts symposia, workshops, and short courses to train scientists from other academic institutions and industrial firms in LC technology, and to facilitate the transfer of technology for commercialization. The eye-catching properties of LC devices are also useful for demonstrating physical principles to public school teachers and students.

Applied Neural Control Laboratory (ANCL)

3480 Charles B. Bolton Building (4912)
http://www.cwru.edu/groups/ANCL/home.html
phone 216-368-3973; fax 216-368-4872
J. Thomas Mortimer, Director
e-mail jtm3@po.cwru.edu

ANCL develops technology and devices to restore missing or impaired human body functions, and participates in transferring findings to industry for commercialization. The emerging technology of applied neural control, based on the electrical stimulation of neural tissue, makes possible the external electrical control of organs or body functions normally controlled by the nervous system.

Applications focus on respiratory assists to patients with acute and chronic respiratory insufficiency; and restoration of limb control and bowel, bladder, and sexual functions in patients with spinal cord injury.

Biomedical engineers are trained at ANCL to gain a working knowledge of fundamental and design aspects of life sciences, material sciences, mechanical engineering, and electrical engineering, which have relevance to applied neural control. Through close association with the highly cross-disciplinary staff affiliated with the laboratory, students and researchers become able to work effectively with the nervous system.

The center conducts an annual research day, to which all interested persons in the community are invited.

Cardiac Bioelectricity Research And Training Center (CBRTC)

509 Wickenden Building (7207)
http://www.cwru.edu/med/CBRTC/
phone 216-368-4051; fax 216-368-4969
Yoram Rudy, Director
e-mail CBRTC@po.cwru.edu

CBRTC fosters interdisciplinary research and training in the fields of cardiac electrophysiology and electrocardiology, in order to enhance understanding of electrical activity and rhythm disorders (arrhythmias) of the heart. It is hoped that this work will lead to improved diagnostic methods and better prevention and treatment strategies. The ultimate aim is to bring about a reduction of fatalities due to arrhythmias (estimated at 400,000 per year in the U.S.) and improved quality of life for afflicted individuals.

Participants in the center include biophysicists, physiologists, biomedical engineers, cardiologists, and surgeons, working synergistically in the research and educational activities related to this field. The educational component builds on the graduate programs in the departments of Biomedical Engineering, and Physiology and Biophysics, and on the Fellowship Program in Clinical Cardiac Electrophysiology. Seminars, case presentations of diagnostic and treatment procedures, clinical lectures, and demonstrations of theoretical modeling of rhythm disorders are periodically conducted. Research is supported by private and government foundations, as well as by industry.

Center for Applied Polymer Research (CAPRI)

422 Kent Hale Smith Building (7202)
http://dione.scl.cwru.edu/cse/emac/Centers/InfoOnDeptCenters.html#CAPRI
phone 216-368-4186; fax 216-368-6329
Anne Hiltner, Director
e-mail pah6@po.cwru.edu

CAPRI performs interdisciplinary applied and basic research on structure-property relationships in polymer materials of interest to industry. Recent work of the center has focused on the attributes of polymer blends and alloys and ways to improve their performance, on processing of micro- and nano-layered materials and structures, on polymers for medical applications, and on new thermoplastics and polyolefin systems.

CAPRI conducts an annual symposium to showcase the center facilities and the research of center graduate and undergraduate students and postdoctoral research associates. CAPRI co-sponsors, with the U.S. Army Research Office, the annual ASILOMAR conference, which features discussions of cutting-edge issues related to polymers and their composites.

CAPRI is supported by several federal agencies, as well as industrial sponsors, 12 of whom serve on its advisory board.

Center For Automation And Intelligent Systems Research (CAISR)

517 Glennan Building (7221)
http://dora.eeap.cwru.edu/
phone 216-368-6248; fax 216-368-6039
Stephen M. Phillips, Director
e-mail smp2@po.cwru.edu

CAISR integrates technologies from several engineering disciplines for basic and applied research in manufacturing, automation and intelligent systems. Basic research in signal processing, feedback control, robotics, nonlinear system analysis, materials science, chemical sensing, neural networks and related topics has been successfully applied to practical problems such as flexible manufacturing, rapid prototyping, rapid manufacturing, machinery diagnostics, torque sensing, lubricant monitoring, intelligent process control, feedback systems with MEMS arrays of sensors and actuators. Faculty and students from six engineering departments work with more than a dozen industrial project sponsors using the computational and laboratory facilities of the center. Facilities include the Intelligent Systems Laboratory, Mechatronics Laboratory, Control Laboratory, Rotating Machinery facility, Agile Manufacturing facility and Computer Aided Manufacturing via Laminated Engineered Materials facility.

Center For Cardiovascular Biomaterials (CCB)

202 Wickenden Building (7207)
http://www.cwru.edu/affil/CCB/ccbhome.htm
phone 216-368-3005; fax 216-368-4969
Roger E. Marchant, Director
e-mail rxm4@po.cwru.edu

CCB, supported by Case Western Reserve, the University of Cincinnati, and The Cleveland Clinic Foundation, carries out research and development projects to investigate biomaterials and devices for use as cardiovascular implants in patients. The chemical and mechanical interface between the biomaterial and the host body are the focus of major study, with the goals being to improve biologic function and biocompatibility in the response of the human body to implants. Current projects include investigation of thrombosis (blood clotting) and infection mechanisms due to cardiovascular prosthesis, biomimetic design of novel biomaterials for cardiovascular and neural implants; cardiovascular and neural tissue engineering, and long-term biodegradation of elastomeric biomaterials. Atomic force microscopy is being used for molecular-level studies on the structure and interactions of blood platelets, and plasma glycoproteins and collagen with biomaterials. Studies at the cell and molecular level assist our understanding of the underlying mechanisms, so that novel biomedical interfaces may be designed, prepared, and characterized. CCB was awarded major grants from The Whitaker Foundation and the Ohio Board of Regents to establish a graduate training program in cardiovascular biomaterials. Students conduct research in this field and pursue integrated engineering and medical science courses. The center plans annual symposia at which participating students discuss their work and outside speakers present topical lectures in the field of cardiovascular biomaterials.

Center For Surface Analysis Of Materials (CSAM)

110 Glennan Building (7204)
phone 216-368-3868; fax 216-368-8932
Arthur H. Heuer, Director
e-mail ahh@po.cwru.edu

The Center for Surface Analysis of Materials and the High Resolution and Analytical Electron Microscopy Facilities provide a comprehensive solution to surface and near-surface microchemical analysis and microstructural characterization needs. The combined facility has 8 analytical instruments devoted to these purposes: 1) NEC 5SDH Ion Beam Accelerator for RBS, PIXE and NRA; 2) PHI 660 Scanning Auger and 3600 SIMS; 3) PHI 5600ESCA (XPS); 4) Philips CM20 STEM with EDS and PEELS; 5) JEOL 4000EX HRTEM; 6) Hitachi S-4500 FEG-SEM; 7) Philips XL30 Environmental SEM with EDS, EBSP, and tensile, heating, and cooling stages; and 8) Scintag X1 Advanced X-Ray Diffractometer with high temperature camera. These instruments are available to campus users and industrial clients for solving a variety of research, development and failure analysis problems that are often encountered in both academia and the industrial environment.

Center On Hierarchical Structures (CHS)

420 Kent Hale Smith Building (7202)
phone 216-368-4203; fax 216-368-6329
Eric Baer, Director
e-mail exb6@po.cwru.edu

The aims of this center are to understand how the unique performance of natural materials arises from precise hierarchical organization, to apply lessons from biology to the design of new hierarchical material systems, and to develop new processes for building complex hierarchical structures. Biological hierarchical paradigms will be used to satisfy societal needs and to solve existing problems.

Edison Polymer Innovation Corporation (EPIC)

Kent Hale Smith Building (7202)
http://dione.scl.cwru.edu/cse/emac/Centers/InfoOnDeptCenters.html#EPIC
phone 216-368-6366; fax 216-368-4028
Jerome B. Lando, President and CEO
e-mail jbl2@po.cwru.edu

EPIC, a partnership between Case Western Reserve, the University of Akron and Ohio State University, carries on research and development in the field of polymers and provides technical service and support, training and education, and problem solving to other academic institutions and to industry. EPIC facilitates the transfer of research results to companies for advanced development and commercialization.

Current EPIC projects include studies of composites and blending, adhesion, polymer films for microelectronics, mechanisms of fatigue and abrasion in rubber and elastomers, three-dimensional flow simulations, and general polymer microstructure studies. EPIC brings together faculty from the departments of macromolecular science, physics, chemistry, electrical engineering, and chemical engineering.

Electronic Design Center (EDC)

112 Bingham Building (7200)
http://www.case.cwru.edu/research/inter.html#electronic
phone 216-368-2934; fax 216-368-8738
Chung-Chiun Liu, Director
e-mail cxl9@po.cwru.edu

EDC carries research and development of advanced chemical and biological sensors for various industrial applications. The center focuses on the applications of microfabrication and micromachining technology to the production of sensor prototypes and other devices. Both silicon and non-silicon materials are used in these developments. The center is a multi-disciplinary educational and research center. Both undergraduate and graduate students use the facility in the center to carry out their research or special projects. Recent microsensor development by researchers in EDC include Schottky diode based hydrogen sensor, high temperature oxygen sensor, nano-structure tin oxide sensor and others. Applications of micromachining techniques to the fabrication of unique microdevices, such as micro-fuel cell and micro-chemical reactor, are also undertaken.

Ernest B. Yeager Center For Electrochemical Sciences (YCES)

404 White Building (7204)
http://electrochem.cwru.edu/yeager/default.htm
phone 216-368-4218; fax 216-368-3209
Joe H. Payer, Director
e-mail jhp@po.cwru.edu

The Ernest B. Yeager Center for Electrochemical Sciences (YCES) promotes and coordinates research and education in electrochemistry at Case Western Reserve University. Electrochemistry and the technologies derived from it are by their nature highly interdisciplinary. They require expertise in fields as widely divergent as surface physics, solid and liquid state physics, electronics, applied mathematics, polymer science, chemical engineering, and, of course, chemistry.

The center facilitates the undertaking of research projects in electrochemistry of a highly interdisciplinary nature, requiring resources and expertise beyond that of any one faculty research group, and usually involving faculty from several of the participating departments. Eight academic departments of the University participate in the center. Approximately 35 faculty from these departments are affiliated with the center's regular members. The center fosters interactions and collaborations among all of the students within these departments who are involved in electrochemical research.

The center serves as an international focal point for electrochemical education. Besides the traditional educating of graduate and postdoctoral students, it offers annual workshops for educating and updating industrial and governmental scientists and engineers. Numerous seminars, special topic symposia and lectureships keep the faculty, students, and the technical community aware of the most recent advances in the field. The center attracts visiting scientists, postdoctoral research associates, and graduate students from the world's leading academic institutions and industrial and governmental laboratories.

The center is to be viewed as a national resource to which industry and government can turn for research and education in electrochemistry.

Microelectromechanical Systems (MEMS)

Bingham Building (7200)
http://mems.cwru.edu/
phone 216-368-0755; fax 216-368-0346
Mehran Mehregany, Director
e-mail mxm31@cwru.edu

Microelectromechanical systems (MEMS) technology provides a microprocessor-compatible means for perception and control at increasingly smaller scales, higher sensitivities, higher throughputs, and lower cost. The associated fabrication technology enables the development of small, functionally sophisticated micromechanical devices (e.g., pressure sensors, inertial sensors, miniature displays, micromechanical light modulators, microvalves, micropumps, etc.) that can be mass-produced at low unit cost.

The University's MEMS research program is interdisciplinary, and targets process and materials technology to develop devices that enable application advancements. Unique silicon carbide MEMS technology strengths are available and are being explored in addition to silicon technology. Application thrusts include: (i) healthcare; (ii) industrial control, automation and fault detection; (iii) portable power generation; and (iv) functional materials and structures.

The Microfabrication Laboratory (MFL), a state-of-the-art facility that provides the latest in micromachining processes, supports the MEMS program involving approximately 10 faculty, several postdoctoral researchers, and approximately 25 graduate students. The MFL is supporting a state-wide network, Ohio MEMSNet, for MEMS research and development.

National Center for Microgravity Research on Fluids and Combustion (NCMR)

103 Crawford Hall (7074)
http://mae1.cwru.edu/mae/
phone 216-368-0748; fax 216-368-0718
Simon Ostrach, Director
e-mail sostrach@ncmr.org

The Universities Space Research Association (USRA) and Case Western Reserve University have established a National Center for Microgravity Research on Fluids and Combustion (NCMR) under the sponsorship of the National Aeronautics and Space Administration (NASA). The National Center is located on the campus of Case Western Reserve and at Glenn Research Center where it will enjoy access to the world-class research facilities of NASA. Housed in the Zero-Gravity Facility of the Space Experiments Laboratory are laboratories for ground research, diagnostics development; a high-bay area, visitor information, flight hardware storage, shipping and receiving as well as office areas. These facilities enable NCMR and NASA to fulfill the rapidly expanding mission in microgravity research and technology development.

At NCMR, critical path research is conducted in support of NASA's mission objectives. For long-term manned space exploration, many mission operations and life-support technologies are crucially affected by fluids and transport phenomena. The center's vision is to become a focal point for microgravity fluids and combustion research that will develop a knowledge base for the design and development of reliable, efficient and cost-effective space systems. A major part of the effort will be to aid in the development of the next-generation technologies that will have to operate for long periods of time in alien environments under extreme conditions. NCMR promotes the idea that "Research for

Design" must be performed to compensate for the limited databases available to designers and builders of space hardware. Through research for design, scientists will become intimately involved at an earlier stage of the hardware development process. To promote free-flow of information, NCMR will hold directed in- and out-reach workshops with industry that will bring together systems engineers, hardware builders and scientists.

Department of Biomedical Engineering

319 Wickenden Building (7207)
Phone 216-368-4063; Fax 216-368-4969
Patrick E. Crago, Chair
e-mail xx220@po.cwru.edu
http://bme.cwru.edu

Background

Biomedical engineering (BME) uniquely advances human health and the biological sciences by creating and applying technology based on phenomena described by the biological and physical sciences. Graduates in biomedical engineering are employed in industry, hospitals, research centers, government, and universities. Biomedical engineers also use their undergraduate training as a basis for careers in business, medicine, law, and other professions.

Biomedical engineering was established in 1968 at Case Western Reserve University. As one of the pioneer programs in the world, we now have a strong and well-established program in research and education with many unique features. It was founded on the premise that engineering principles provide an important basis for innovative and unique solutions to biomedical problems. This philosophy has been the guide for the successful development of our program, which has been emulated by many other institutions. Quantitative engineering for biomedical applications remains the cornerstone of our program and distinguishes it from biomedical science programs. In addition to dealing with biomedical problems at the tissue and organ-system level, our educational programs have a growing emphasis on cellular and subcellular mechanisms for understanding of fundamental processes as well as for systems approaches to solving clinical problems. Current programs lead to the B.S., M.S., combined B.S./M.S., Ph.D., and MD/Ph.D. in biomedical engineering. In all of the BME programs at Case Western Reserve, the goal is to educate engineers who can apply engineering methods to problems involving living systems. The Case School of Engineering and the School of Medicine are located in close proximity on the same campus. The Biomedical Engineering faculty carry joint appointments in the two schools and participate fully in the teaching, research, and decision-making committees of both schools. The department is in close proximity to several major medical centers (University Hospitals, Cleveland Clinic Foundation, The VA Medical Center, and MetroHealth Medical Center). As a result, we have an unusually free flow of academic exchange and collaboration in research and education among the Schools and Institutions. Our BME programs take full advantage of faculty cooperation among University departments, which adds significant strength to our programs.

The educational philosophy is to develop in students

Mastery of Fundamentals

- Acquire a strong integrated background in the fundamentals of mathematical, chemical, physical, and biomedical sciences and engineering.
- Become knowledgeable in a special discipline of biomedical engineering such as biomaterials, tissue engineering, biomechanics, instrumentation, biomedical imaging, biomedical sensors, modeling, and biomedical systems.
- Measure phenomena relevant to medicine and biology using state-of-the-art instrumentation.
- Describe biomedical phenomena by mathematical modeling

Creativity

- Design devices, materials, instruments, models, and software for biomedical science and health applications.
- Expand the knowledge base through innovative approaches to biomedical research

Societal Awareness

- Understand issues presented by the biomedical community, and translate them into solvable engineering problems.
- Recognize the role of biomedical engineering in developing technology for commercial application and economic development of society.

Leadership Skills

- Communicate technical information to both technical and non-technical audiences.
- Work effectively in a team setting with others of differing backgrounds.

Professionalism

- Recognize and respond to biomedical ethical issues.
- Acquire skills for self-instruction and life-long learning.

Faculty

Primary Appointments

Patrick E. Crago, Ph.D. (Case Western Reserve University)
Professor and Chairperson; Allen H. and Constance T. Ford Professor
Control of neuroprotheses for motor function; neuromuscular control systems

Ravi V. Bellamkonda (Brown University)
Associate Professor
Biomaterials; neural tissue engineering; 3D hydrogel based scaffolds; gene and protein delivery vehicles; vascular grafts and nerve regeneration

Jianmim Cui, Ph.D. (State University of New York - Stony Brook)
Assistant Professor
Molecular and biophysical mechanisms of ion channel function and modulation; the role of ion channels in cardiac excitation and arrhythmias

Cheri Deng, Ph.D. (Yale University)
Elmer W. Lindseth Assistant Professor, Biomedical Engineering
Research in ultrasound, contrast agents and angiogenesis

Dominique Durand, Ph.D. (University of Toronto, Canada)
Professor
Director, Neural Engineering Center
Neural engineering; neuroprostheses; neural dynamics; electric and magnetic stimulation of the nervous system; neural interfaces with electronic devices; analysis and control of epilepsy

Steven J. Eppell, Ph.D. (Case Western Reserve University)
Assistant Professor
Nanoscale instrumentation for biomaterials; bone and cartilage

Igor Efimov, Ph.D. (Moscow Institute of Physics & Technology)
Elmer W. Lindseth Associate Professor of Biomedical Engineering
Fast fluorescent imaging of the heart. Mechanisms of arrhythmogenesis and antiarrhythmic therapies. Mechanisms of stimulation and defibrillation of the heart

Jinming Gao, Ph.D. (Harvard University)
Assistant Professor
Biomolecular engineering; imaging-guided drug delivery; controlled-release drug delivery; elastic biomaterials

Miklos Gratzl, Ph.D. (Technical University of Budapest, Hungary)
Associate Professor
Biochemical sensors; fine chemical manipulation of microdroplets and single cells; cancer research and neurochemistry at the single cell level; cost-effective biochemical diagnostics in microliter body fluids

Warren M. Grill, Ph.D. (Case Western Reserve University)
Assistant Professor of Biomedical Engineering
Neural engineering and neural prostheses; modeling and simulation of stimulation and electrodes; neural control of genitourinary and motor function; anatomy and neurochemistry of neural circuits

Robert F. Kirsch, Ph.D. (Northwestern University)
Associate Professor
Functional neuromuscular stimulation; biomechanics and neural control of human movement; modeling and simulation of musculoskeletal systems; identification of physiological systems

Dmitri E. Kourennyi, Ph.D. (Moscow Institute of Physics & Technology)
Assistant Professor
Synaptic transmission and networking in the retina; ion channels; biophysics, pharmacology, modulation; second messengers in neurons; nitric oxide functional and pathological roles; signal processing in the retina

Roger Marchant, Ph.D. (Case Western Reserve University)
Professor
Director, Center for Cardiovascular Biomaterials
Surface modification of cardiovascular devices; molecular level structure and function of plasma proteins; liposome drug delivery systems; mechanisms of bacterial adhesion to biomaterials

J. Thomas Mortimer, Ph.D. (Case Western Reserve University)
Professor Emeritus
Director, Applied Neural Control Laboratory
Neural prostheses; electrical activation of the nervous system; bowel and bladder assist device; respiratory assist device; selective stimulation and electrode development; electochemical aspects of electrical stimulation

Niels F. Otani, Ph.D. (University of California, Berkeley)
Associate Professor
Cardiac bioelectricity and excitable tissues; simulation of cardiac action potential propagation; nonlinear dynamics applied to excitable tissues; improved drug therapies and electrical intervention strategies for arrhythmias

P. Hunter Peckham, Ph.D. (Case Western Reserve University)
Professor
Director, Functional Electrical Stimulation Center
Neural prostheses, implantable stimulation and control; control of movement; rehabilitation engineering

Andrew M. Rollins, Ph.D. (Case Western Reserve University)
Assistant Professor, Biomedical Engineering
Biomedical diagnosis, novel optical methods for high-resolution, minimally invasive imaging, tissue characterization and analyte sensing, real-time microstructural and functional imaging using coherence tomography

Yoram Rudy, Ph.D. (Case Western Reserve University)
M. Frank & Margaret C. Rudy Professor of Cardiac Bioelectricity
Director, Cardiac Bioelectricity Research & Training Center (CBRTC)
Cardiac bioelectricity and electrophysiology of the heart; modeling cardiac excitation and arrhythmias at the cellular, tissue, and whole heart levels; cardiac mapping; noninvasive imaging of cardiac electrical function and arrhythmias

Gerald M. Saidel, Ph.D. (The Johns Hopkins University)
Professor
Mass & heat transport and metabolic analysis in cells, tissues, & organs; mathematical modeling, simulation, parameter estimation; optimal experimental design; metabolic dynamics; minimally invasive thermal tumor ablation; slow release drug delivery

David L. Wilson, Ph.D. (Rice University)
Professor
Medical image processing; image segmentation, registration, and analysis; quantitative image quality of X-ray fluoroscopy and fast MRI; interventional MRI treatment of cancer

Secondary Appointments

James M. Anderson, Ph.D. (Oregon State University), M.D. (Case Western Reserve University)
Professor, Pathology, University Hospitals
Biocompatibility of implants

Harihara Baskaran, Ph.D. (Pennsylvania State University)
Assistant Professor, Chemical Engineering, Case Western Reserve University

Marco Cabrera, Ph.D. (Case Western Reserve University)
Assistant Professor, Pediatric Cardiology
Modeling and control of metabolic processes; metabolic regulation in hypoxia, ischaemia and exercise

Ronald L. Cechner, Ph.D. (Case Western Reserve University)
Associate Professor, Anesthesiology, University Hospitals Microscopic 3-D imaging of tissue

John Chae, M.D. (New Jersey Medical School)
Assistant Professor, Physical Medicine and Rehabilitation
Application of neuroprotheses in hemiplegia

Hillel J. Chiel, Ph.D. (Massachusetts Institute of Technology)
Professor, Biology
Biomechanical and neural basis of feeding behavior in the marine mollusk Aplysia californica; neuromechanical system modeling; analysis of neural network dynamics

David Dean, Ph.D. (City University of New York)
Assistant Professor, Neurosurgery and Anatomy, University Hospitals
Morphometrics; craniofacial imaging

Louis F. Dell'Osso, Ph.D. (University of Wyoming)
Professor, Neurology, VA Medical Center
Neurophysiological and ocular motor control systems

Pedro J. Diaz, Ph.D. (Case Western Reserve University)
Assistant Professor, Radiology, MetroHealth Medical Center
Magnetic resonance imaging; image processing

Jeffrey L. Duerk, Ph.D. (Case Western Reserve University)
Professor, Radiology, University Hospitals
Magnetic resonance imaging; flow visualization

Brian Johnstone, Ph.D. (University College, University of London)
Assistant Professor, Orthopaedics, Case Western Reserve University

Michael W. Keith, M.D. (Ohio State University)
Professor, Orthopaedic Surgery, MetroHealth Medical Center
Restoration of motor function in hands

Kenneth R. Laurita, Ph.D. (Case Western Reserve University)
Assistant Professor, Cardiology, MetroHealth Medical Center
Optical imaging in cardiac electrophysiology

Zhenghong Lee, Ph.D. (Case Western Reserve University)
Assistant Professor, Radiology, Nuclear Medicine, University Hospitals

R. John Leigh, M.D. (University of Newcastle-Upon-Tyne, U.K.)
Professor, Neurology, VA Medical Center
Normal and abnormal motor control of the eye

Jonathan Lewin, M.D., Ph.D., (Yale University)
Professor, Radiology, University Hospitals

Raymond F. Muzic, Jr., Ph.D. (Case Western Reserve University)
Associate Professor, Radiology, University Hospitals
Experiment design and analysis for positron emission tomography

David S. Rosenbaum, M.D. (University of Illinois, Chicago)
Associate Professor, Medicine, MetroHealth Medical Center
Optical imaging in cardiac electrophysiology

Mark S. Rzeszotarski, Ph.D. (Case Western Reserve University)
Assistant Professor, Radiology, MetroHealth Medical Center
Radiological imaging; magnetic resonance imaging, ultrasound

Ronald J. Triolo, Ph.D. (Drexel University)
Associate Professor, Orthopaedics, VA Medical Center
Restoration of lower extremity function

Albert L. Waldo, M.D. (State University of New York)
Professor, Cardiology, University Hospitals
Cardiac electrophysiology and cardiac excitation mapping

Nicholas P. Ziats, Ph.D. (Case Western Reserve University)
Assistant Professor, Pathology, University Hospitals
Vascular grafts; vascular cells; blood vessels

Adjunct Appointments

Richard C. Burgess, M.D., Ph.D. (Case Western Reserve University)
Adjunct Professor of Biomedical Engineering (Neurological Computing, Cleveland Clinic Foundation)

Brian Davis, Ph.D. (Pennsylvania State University)
Adjunct Assistant Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Human locomotion and biomechanics

Linda M. Graham, M.D. (University of Michigan)
Adjunct Professor of Biomedical Engineering (Vascular Surgery and Biomedical Engineering, Cleveland Clinic Foundation)

Hiroaki Harasaki, Ph.D., M.D. (Kyushu University, Japan)
Adjunct Associate Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Artificial heart; blood-surface interactions

Vincent J. Hetherington, D.P.M. (Pennsylvania College of Podiatric Medicine)
Adjunct Assistant Professor of Biomedical Engineering (Surgery, Ohio College of Podiatric Medicine)
Biomaterials and biomechanics of foot prostheses

David Huang, Ph.D. (Massachusetts Institute of Technology), M.D. (Harvard University)
Adjunct Assistant Professor of Biomedical Engineering (Opthalmology, Cleveland Clinic Foundation)
Optical coherence tomography of the eye, laser vision correction, corneal wound healing, corneal topography

Joseph Izatt (Massachusetts Institute of Technology)
Adjunct Associate Professor (Biomedical Engineering, Duke University)

Bachelor of Science in Engineering Degree Major in Biomedical Engineering [a]

Freshman Year

Fall

Course	Class-Lab-Credit Hours
EBME 105, Introduction to Biomedical Engineering [b]	(3-0-3)
CHEM 111, Chemistry for Engineers	(4-0-4)
MATH 121, Calculus for Science and Engineering I	(4-0-4)
ENGR 131, Elementary Computer Programming	(2-2-3)
ENGL 150, Expository Writing	(3-0-3)
PHED 101, Physical Education	(0-3-0)
Total	**(16-5-17)**

Spring

Course	Class-Lab-Credit Hours
ENGR 145, Chemistry of Materials	(4-0-4)
MATH 122, Calculus for Science and Engineering II	(4-0-4)
PHYS 121, General Physics I	(4-0-4)
H/SS	(3-0-3)
PHED 102, Physical Education	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

Course	Class-Lab-Credit Hours
EBME 201, Physiology - Biophysics I	(3-0-3)
MATH 223, Calculus for Science and Engineering III	(3-0-3)
PHYS 122, General Physics II	(4-0-4)
BME Specialty Sequence [c] or Science Elective [d]	(3-0-3)
H/SS	(3-0-3)
Total	**(16-0-16)**

Spring

Course	Class-Lab-Credit Hours
EBME 202, Physiology - Biophysics II	(3-0-3)
MATH 234, Intro to Dynamic Systems	(3-0-3)
ENGR 210, Intro to Circuits & Instrumentation	(3-3-4)
BME Specialty Sequence [c] or Science Elective [d]	(3-0-3)
H/SS	(3-0-3)
Total	**(15-3-16)**

Junior Year

Fall

Course	Class-Lab-Credit Hours
EBME 306, Introduction to Biomaterials	(3-0-3)
EBME 313, Biomedical Engineering Lab I	(1-3-2)
ENGL 398N, Professional Communication	(3-0-3)
EBME 308, Biomedical Systems & Circuits	(3-3-4)
ENGR 225, Thermo, Fluids, Heat & Mass Transfer	(4-0-4)
Total	**(14-6-16)**

Spring

Course	Class-Lab-Credit Hours
EBME 314, Biomedical Engineering Lab II	(1-3-2)
EBME 310, Principles of Biomedical Instrumentation	(3-0-3)
EBME 360, BME Instrumentation Lab	(0-3-1)
ENGR 200, Mechanics and Materials	(3-0-3)
H/SS	(3-0-3)
BME Specialty Sequence [c]	(3-0-3)
BME Specialty Sequence [c]	(3-0-3)
Total	**(16-6-18)**

Senior Year

Fall

Course	Class-Lab-Credit Hours
EBME 398, Senior Project	(0-9-3)
or EBME 380, Design in BME	(1-6-3)
BME Specialty Sequence [c]	(3-0-3)
BME Specialty Sequence [c]	(3-0-3)
Statistics [e]	(3-0-3)
H/SS	(3-0-3)
Total	**(12-9-15) or (13-6-15)**

Spring

Course	Class-Lab-Credit Hours
EBME 309, Modeling of Biomedical Systems	(3-0-3)
EBME 359, BME Computer Simulation Lab	(0-3-1)
BME Specialty Sequence [c]	(3-0-3)
H/SS	(3-0-3)
BME Specialty Sequence [c]	(3-0-3)
Open Elective	(3-0-3)
Total	**(15-3-16)**

a. This is a typical program. Specialty sequences are designed with courses in a desired order that might vary from the one here. Programs must be planned with a faculty adviser in the Department of Biomedical Engineering.
b. This optional course is limited to freshmen. This can be replaced by an open elective.
c. Courses are chosen depending on the BME specialty sequence as listed below.
d. Students take at least one math or science course approved by BME department.
e. STAT 312, STAT 333, or STAT 332 fulfill the statistics requirement. Check with sequence advisor to determine the most appropriate class.

J. Lawrence Katz, Ph.D. (Polytechnic Institute of Brooklyn)
Adjunct Professor (University of Missouri, Kansas City)
Bone biomechanics and biomaterials; bone mineral crystallography; ultrasonic wave propagation; scanning acoustic microscopy; dental and orthopaedic implants

Jill W. Kawalec, Ph.D. (Case Western Reserve University)
Adjunct Assistant Professor of Biomedical Engineering (Research Director, Ohio College of Podiatric Medicine)
Biomaterials and biomechanics of foot prostheses

Kevin L. Kilgore, Ph.D. (Case Western Reserve University)
Adjunct Assistant Professor of Biomedical Engineering (Orthopaedics, MetroHealth Medical Center)
Functional electrical stimulation; hand protheses

Melissa Knothe-Tate, Ph.D. (University & Swiss Federal Institute of Technology, Zürich, CH)
Adjunct Assistant Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)

Kandice Kottke-Marchant, Ph.D., M.D. (Case Western Reserve University)
Adjunct Professor of Biomedical Engineering (Hematology, Cleveland Clinic Foundation)
Interaction of blood and materials

William Landis, Ph.D. (Massachusetts Institute of Technology)
Adjunct Professor of Biomedical Engineering (Department of Biochemistry and Molecular Pathology, Northeastern Ohio Universities College of Medicine)
Mineralization of vertebrates, effect of mechanical force on mineralization, calcium transport in mineralization, tissue engineering

Marc Penn, M.D., Ph.D. (Case Western Reserve University)
Adjunct Assistant Professor of Biomedical Engineering (Cardiology and Cell Biology, Cleveland Clinic Foundation)

Kimerly Powell, Ph.D. (Ohio State University)
Adjunct Associate Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Image post-processing for detection and diagnosis of breast cancer and quantitative microscopy

Antonie J. van den Bogert, Ph.D. (University of Utrecht)
Adjunct Assistant Professor of Biomedican Engineering (Biomedical Engineering, Cleveland Clinic Foundation)

Ivan Vesely, Ph.D. (University of Western Ontario, Canada)
Adjunct Associate Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Micromechanics of heart valves; fatigue of soft tissue

Geoffrey D.Vince, Ph.D. (University of Liverpool Medical School, United Kingdom)
Adjunct Assistant Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Image and signal processing of intravascular ultrasound images, mechanics of coronary plaque rupture, cellular aspects of atherosclerosis

Michael Wendt, Ph.D. (University of Witten/Herdecke, Germany)
Adjunct Assistant Professor of Biomedical Engineering (Siemens Medical Solutions, USA, Inc.)
Interventional magnetic resonance imaging; wavelet encoding

Guang Yue, Ph.D. (University of Iowa)
Adjunct Assistant Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Neural control of movement

Maciej Zborowski, Ph.D. (Polish Academy of Science)
Adjunct Assistant Professor of Biomedical Engineering (Biomedical Engineering, Cleveland Clinic Foundation)
Membrane separation of blood proteins

Undergraduate Programs

The Case Western Reserve undergraduate program leading to the Bachelor of Science degree with a major in biomedical engineering was established in 1972. The B.S. program in BME is accredited by the Accreditation Board of Engineering and Technology.

The educational objective of our undergraduate program is to develop in our students problem-solving skills, the ability to think independently, and the ability to assess ideas with an open mind, which will allow them to be successful as they go on in careers in biomedical engineering, to medical school, or to graduate school in biomedical engineering. Specifically, our goal is to develop in students the ability to:

BME Specialty Sequence Classes

To ensure depth in a particular area, students take one of the seven specialty sequences listed below. Students should consult the website of the Department of Biomedical Engineering to learn more about the educational program and to determine the best order for taking courses in a particular sequence.

Biomechanics

EMAE 181, ECIV 310, EMAE 250, EMAE 271, and EMAE 372; and technical electives from EBME 307, EBME 311, EBME 324, EBME 402, EMAE 377, EMAE 350, EBME 307, EMAE 415, EMAE 370

Biomaterials (polymeric)

EMAC 270, CHEM 223, EMAC 351, and EBME 303; and technical electives from EBME 416, EBME 405, EMAC 377, ECHE 360, EBME 311, EMAC 376, EBME 406, EBME 408, EMAC 276, and EMAC 352, EMAC 351, and EMAC 377.

Biomaterials (orthapedic)

EMSE 201, ECIV 310, EMSE 303, and EMAC 270; and technical electives from EBME 405, EMSE 316, EBME 416, EMSE 202, EMSE 270, EMSE 313, EMSE 411, EMAE 372, EMAC 276, EMAC 250, EBME 303, EBME 311, EBME 406, EBME 408, EMAE 415

Biomaterials (Tissue Engineering)

CHEM 223, ECHE 360, EMAC 270, and ECHE 340; and technical electives such as EBME 405, EBME 416, EMAC 377, BIOC 307, CBIO 453, EBME 406, EBME 408, ECHE 364, EMAC 376, BIOC 308, and EBME 303.

Biomedical Computing & Imaging

ECES 233, ECES 337, and EBME 320; and technical electives from ECES 281, EBME 431, ECES 375, EBME 324, ECES 340, ECES 391, MIDS 329, EBME 461, ECES 375, ECES 341, ECES 338, and MATH 304

Biomedical Instrumentation (devices)

ECES 245, ECES 281, and ECES 344; and technical electives from EEAP 382, EEAP 309, ECES 313, EBME 403, EBME 320, EBME 324, ECES 321, ECES 311, EBME 418, PHYS 326, ECES 282, ECES 322, ECES 344, ECHE 370, ECHE 380, and ECHE 381.

Biomedical Systems & Control

ECES 304, ECES 313, ECES 322, and EMAE 181; and technical electives ECES 306, MATH 201, EBME 324, OPRE 345, EBME 402, EBME 407, EBME 320, MATH 201, OPRE 345, EBME 461, EMBE 307, and ECES 346.

Notes

This gives 129 credits. Varies from sequence to sequence.

1. Construct models of biomedical systems, and solve them using a combination of modern computer applications and theory,
2. Measure physical phenomena relevant to medicine and biology using state-of-the-art instrumentation,
3. Design electronic instruments useful to the medical community,
4. Understand problems presented by the medical community, and translate them into solvable engineering problems,
5. Write effectively in a technical style,
6. Speak effectively to both technical and non-technical audiences, and
7. Work effectively in a team setting.

To be successful in developing the subset of skills technical in nature in the list above:

8. Students must be well-trained in biological, mathematical, scientific, and engineering fundamentals.

Students, upon graduating from our program, should be:

9. Aware of real-life contemporary biomedical problems,
10. Sensitive to biomedical ethical issues,
11. Knowledgeable in one of the specialty areas central to the discipline of biomedical engineering.

Some B.S. graduates are employed in industry and medical centers. Others continue studies in biomedical engineering and other fields. Students with engineering ability and an interest in medicine may consider the undergraduate biomedical engineering program as an exciting alternative to conventional premedical programs. The undergraduate program has three major components (1) Engineering Core, (2) BME Core, and (3) BME Specialty Sequence. The Engineering Core provides a broad background in mathematics, sciences, and engineering. A typical program of study is shown in the table. The BME Core integrates engineering with biomedical science to solve biomedical problems. Hands-on experience in BME is developed through the undergraduate laboratory and project courses. In addition, by choosing a BME specialty sequence, the student can learn in depth about a specific area. This integrated program is designed to ensure that BME graduates are competent engineers. Students may select open electives for educational breadth or depth or to meet entrance requirements of medical school or other professional career choices. BME faculty serve as student advisors to guide students in choosing the program of study most appropriate for individual needs and interests.

Biomedical Engineering Specialty Electives

Common BME specialties are biomaterials (orthopaedic, polymeric, tissue engineering), biomechanics (prosthetics and tissues), biomedical instrumentation (devices & sensors), biomedical computing and imaging, and biomedical systems & control. Courses for these specialties are presented in the table. Complete descriptions and suggested schedules for approved specialties are available on the department's web page (bme.cwru.edu). These specialties provide the student with a solid background in a well-defined area of biomedical engineering. To meet specific educational needs, students may choose alternatives from among the suggested electives or design unique specialties subject to departmental guidelines and faculty approval.

Co-op and Internship Programs

Opportunities are available for students to alternate studies and work in industry as a co-op student, which is integrated in a 5-year program. Alternatively, students may obtain employment as summer interns.

Minor in Biomedical Engineering

A minor in biomedical engineering is offered to students who have taken the Engineering Core requirements. The minor consists of 15 credit hours based on two required courses, EMBE 201/EBME 202 and an approved set of three electives chosen from among EBME 303, EMBE 306, EBME 308, EBME 309/359, EBME 310/360, EBME 311, EBME 320, and EBME 324.

B.S./M.S. Program

Undergraduates with a strong academic record may apply in their junior year for admission to the integrated B.S./M.S. program. A senior research project that begins in the summer after the junior year is designed to expand into an M.S. thesis. Also, the student begins to take graduate courses in the senior year. With continuous progress in research during three summers and the academic years, this program can lead to both the B.S. and M.S. in 5 years.

Graduate Programs

The objective of our graduate education program is to educate biomedical engineers for careers in industry, academia, health care, and government, and to advance research in biomedical engineering. The department provides a learning environment that encourages students to apply biomedical engineering methods to advance basic scientific discovery, integrate knowledge across the spectrum from basic cellular and molecular biology through tissue, organ, and whole body physiology and pathophysiology, and to exploit this knowledge to design diagnostic and therapeutic technologies that improve human health. The unique and rich medical, science, and engineering environment allows research projects ranging from basic science through engineering design and clinical application.

Numerous fellowships and research assistantships are available to support graduate students in their studies.

M.S. Programs

The M.S. program in biomedical engineering provides breadth in biomedical engineering and biomedical sciences with depth in an engineering specialty. In addition, students are expected to develop the ability to work independently on a biomedical research or design project. The M.S. requires a minimum of 30 credit hours. With an M.S. research thesis (Plan A), a minimum of 21 credits hours is needed in regular course work and 9 hours of thesis research (EBME 651). With an M.S. project (Plan B), a minimum of 27 credits hours is needed in regular course work, and three hours of project research (EBME 601).

Master of Engineering and Management - Biomedical Entrepreneurship

Biomedical engineering students may apply for the Biomedical Entrepreneurship concentration in the Master of Engineering (MEM) program. The MEM is a joint degree offered by The Institute for the Integration of Management and Engineering (TIIME), in the Case School of Engineering and the Weatherhead School of Management. The objective of this program is to provide biomedical engineers with the business and management context required to enable them to drive innovation within biomedical companies while serving in a technical capacity.

Students can enter the program as undergradautes. The program does not interfere with undergradaute degree requirements. The curriculum inclues courses integrating engineering and management, as well as industrial internships. By making use of summers for both course work and internships, the degree is completed in one additional year beyond the B.S., for a total of five years.

Students should apply through TIIME.

Ph.D. Program in Biomedical Engineering

For those students with primary interest in research, the Ph.D. in biomedical engineering provides additional depth and breadth in engineering and the biomedical sciences. Under faculty guidance, students are expected to undertake original research motivated by a biomedical problem. Research possibilities include the development of new theory, devices, or methods for diagnostic or therapeutic applications as well as for measurement and evaluation of basic biological mechanisms.

The Ph.D. program requires a minimum of 13 courses beyond the B.S. degree. There are four required core courses (EBME 403, 409, 451, 452). The balance of the courses can be chosen with significant flexibility to meet the career goals of the student, and to satisfy requirements of depth and breadth. Programs of study must include three graduate level courses in biomedical sciences and two courses whose content is primarily mathematical. Two semesters of departmental seminar attendance (EBME 611, 612) and three semesters of teaching experience (EBME 400T, 500T, 600T) are also required. Ph.D. programs of study are reviewed and must be accepted by the Graduate Education Committee and the department chairperson. Eighteen hours of EBME 701 registration are required.

Ph.D. candidacy requires passing certain milestones. A student is advanced to Ph.D. candidacy after passing the Ph.D. Qualifying Exam and obtaining approval of the Ph.D. short proposal. The Ph.D. is completed when the dissertation has been written and defended, and when at least two manuscripts have been submitted for publication and at least one of the two is accepted.

Ph.D. Program in Biophysics-Bioengineering

This program, which is administered through the School of Medicine is jointly sponsored with the Department of Physiology and Biophysics. A full description is available in the section on the School of Medicine.

Ph.D. Program in Neuroscience-Bioengineering

This program, which is administered through the School of Medicine is jointly sponsored with the Department of Neurosciences. A full description is available in the section on the School of Medicine.

Ph.D./M.D. Programs

Students with outstanding qualifications may apply to either of two M.D./Ph.D. programs. Students interested in obtaining a combined M.D./Ph.D., with an emphasis on basic research in biomedical engineering, are strongly encouraged to explore the Medical Scientist Training Program (MSTP), administered by the School of Medicine. Alternatively, the Physician Engineer Training Program (PETP) was established to train future physicians who also possess expertise in state-of-the-art engineering medical technologies, with a research focus on applied biomedical engineering. The PETP is admiinstered through the BME Department. It is expected that graduates of the PETP will have a strong interest in the biomedical industrial sector, clinical medicine, or in academic positions in biomedical engineering, rather than the traditional M.D./Ph.D. career pathway in academic medicine.

Both M.D./Ph.D. programs require approximately 7-8 years of intensive study after the B.S.

Research Areas

Several research thrusts are available to accommodate various student backgrounds and interests. Strong research collaborations with clinical and basic science departments of the university and collaborating hospitals bring a broad range of opportunities, expertise, and perspective to student research projects.

Biomaterials/Tissue Eengineering

Materials for implantation, including neural and cardiovascular tissue engineering, biomimetic materials, liposomal and controlled drug delivery, and biocompatible polymer surface modifications. Analysis of synthetic and biologic polymers by AFM, nanoscale structure-function relationships of orthopedic biomaterials.

Biomedical Image Processing and Analysis

MRI, PET, untrasound, optical coherence tomography, cardiac electrical potential mapping, human visual perception, image guided intervention.

Biomedical Sensing

Optical sensing, electrochemical and chemical fiber-optic sensors, chemical measurements in cells and tissues, endoscopy.

Cardiac Bioelectricity

Cardiac electrophysiology (at ion-channel, cell, and tissue levels), models of cellular activity, mechanisms of cardiac arrhythmias, optical imaging of electrical propagation in the heart, noninvasive electrocardiographic imaging.

Neural Engineering and Neural Prostheses

Neuronal mechanisms; neural interfacing for electric and magnetic stimulation and recording; neural dynamics, ion channels, second messengers, nitric oxide, signal processing in the retina; neural prostheses for control of limb movement, bladder, bowel, and respiratory function.

Transport and Metabolic Systems Engineering

Modeling and analysis of tissue responses to heating (tumor ablation, implanted artificial heart) and of cellular metabolism related to organ and whole-body function in health (exercise) and disease (cardiac).

Facilities

The administrative offices of the Department of Biomedical Engineering are located in the Wickenden Building, which houses many BME research laboratories as well as the Center for Cardiovascular Biomaterials (CCB) and the Cardiac Bioelectricity Research and Training Center (CBRTC). Within the CCB are the laboratories for biomaterials microscopy, biopolymer & biomaterial interfaces, and molecular simulation. Other biomaterials related laboratories include Cell and Tissue Engineering and Biomaterials Protein Engineering. The CBRTC includes laboratories for High-Performance Cardiac Simulation and Display, Cardiac Cell Experiments, Cardiac Cell Imaging, and Cardiac Optical and Electrical Mapping. Optical laboratories deal with Microspectroscopic Diagnostics and Fiberoptic Biosensors. Diagnostic optical and electrochemical techniques are developed in the laboratory for Microchemical Sensors. The laboratory for Biomedical Image Processing and Analysis works on images from the molecular level to the tissue-organ level. Primary BME faculty are also directors of laboratories in other locations. The Endoscopy Research Laboratory is the center for work on Optical Computed Tomography. The Applied Neural Control Laboratory is a major facility for basic research and animal experimentation in the development of neural prostheses. The Neural Engineering Center and Laboratory is a major facility for basic research and animal experimentation. The focus is on recording and controlling neural activity to increase our understanding of the nervous system and to develop neural prostheses. The Functional Electrical Stimulation Center develops techniques for restoration of movement in paralysis, control of the nervous system, and implantable technology. Also, it promotes technology transfer and disseminates information about biomedical electrical stimulation. The Rehabilitation Engineering Center evaluates clinical functionality of neuroprostheses.

The department faculty and students have access to the facilities and major laboratories of the Case School of Engineering and of the School of Medicine. Faculty have numerous collaborations at University Hospitals, MetroHealth Medical Center, VA Medical Center, and the Cleveland Clinic Foundation. These provide extensive research resources in a clinical environment for both undergraduate and graduate students.

Biomedical Engineering (EBME)

Undergraduate Courses

EBME 105. Introduction to Biomedical Engineering (3)
Biomedical engineering fields of activity. Research, development, and design for biomedical problems, diagnosis of disease, and therapeutic applications.

EBME 201. Physiology-Biophysics I (3)
Cell physiology. Electrophysiology of nerve and muscle. Motor system. Central nervous system. Sensory systems. Autonomic nervous system.

EBME 202. Physiology-Biophysics II (3)
Biological control systems. Cardiovascular, renal, respiratory, gastro-intestinal, and immune systems.

EBME 300. Dynamics of Biological Systems: A Quantitative Introduction to Biology (3)
(See BIOL 300.) Cross-listed as BIOL 300.

EBME 303. Structure of Biological Materials (3)
Structure of proteins, nucleic acids, connective tissue and bone from molecular to microscopic levels. Principles and applications of instruments for imaging, identification, and measurement of biological materials. Prereq: EBME 202. Cross-listed as EMAC 303.

EBME 306. Introduction to Biomedical Materials (3)
Applications of biomaterials in different tissue and organ systems. Relationship between physical and chemical structure of materials and biological system response. Choosing, fabricating and modifying materials for specific biomedical applications. Prereq: EBME 201 and EBME 202.

EBME 307. Biomechanical Prosthetic Systems (3)
Introduction to the basic biomechanics of human movement and applications to the design and evaluation of artificial devices intended to restore or improve movement lost due to injury or disease. Measurement techniques in movement biomechanics, including motion analysis, electromyography, and gait analysis. Design and use of upper and lower limb prostheses. Principles of neuroprostheses with applications to paralyzed upper and lower extremities.

EBME 308. Biomedical Signals and Systems (4)
Quantitative analysis of biomedical signals and physiological systems. System classification. Fourier and Laplace transforms. Frequency response of systems and circuits. A/D conversion, sampling, and discrete-time signal processing. Filter design. Laboratory and computational experiences with biomedical applications. Prereq: EBME 201, EBME 202, and ENGR 210.

EBME 309. Modeling of Biomedical Systems (3)
Mathematical modeling and computer simulation techniques with biomedical applications. Nonlinear dynamics and finite difference equations as applied to cellular and physiological systems. Theoretical models of excitable tissues (nerve and muscle). Application of electromagnetic field theory to bioelectric systems. Volume conductor fields generated by nerve, muscle, and cardiac excitation.

EBME 310. Principles of Biomedical Instrumentation (3)
Physical, chemical and biological principles for biomedical measurements. Modular blocks and system integration. Sensors for displacement, force, pressure, flow, temperature, biopotentials, chemical composition of body fluids and biomaterial characterization. Patient safety. Prereq: EBME 308.

EBME 311. Artificial Organs (3)
Engineering for replacement of kidney, lung, heart, and other organ functions. Chemical, electrical, mechanical, materials, pathological and surgical aspects. Prereq: EBME 202, EBME 308 and ENGR 210.

EBME 313. Biomedical Engineering Laboratory I (2)
Experiments for measurement, assisting, replacement, or control of various biomedical systems. Prereq: EBME 201, EBME 202 and ENGR 210. Coreq: ENGL 398N.

EBME 314. Biomedical Engineering Laboratory II (2)
Continuation of EBME 313. Prereq: EBME 201, EBME 202 and ENGR 210.

EBME 320. Medical Imaging Fundamentals (3)
Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Prereq: EBME 201, EBME 202, EBME 308, and EBME 310 or equivalent.

EBME 324. Laboratory Computing in Biomedical Engineering (3)
Hardware and software aspects of computer systems for laboratory application. Analog and digital interfacing. Signal conditioning and sampling requirements. Computer control of laboratory instruments and data acquisition. Biomedical applications. Prereq: EBME 201, EBME 202, and EBME 308.

EBME 350. Quantitative Molecular Bioengineering (3)
The teaching objective of this course is to equip the students with a "molecular toolbox"—a set of quantitative skills that permit intelligent designs of engineering solutions for medical problems at the molecular level. The core of the course will build on the physical and chemical principles in equilibrium, kinetics, and mass transport. Specific biomedical examples in bioengineering systems will be used throughout the course to illustrate the importance of understanding and application of these principles in problem solving. Prereq: ENGR 225.

EBME 359. Biomedical Computer Simulation Laboratory (1)
Computer simulation and mathematical models of biomedical systems. MATLAB software tools are used to demonstrate the basic properties of dynamical systems, numerical methods and their application to biomedical problems. Coreq: EBME 309.

EBME 360. Biomedical Instrumentation Laboratory (1)
A laboratory which focuses on the basic components of biomedical instrumentation and provides hands-on experience for students in EBME 310, Biomedical Instrumentation. The purpose of the course is to develop design skills and laboratory skills in analysis and circuit development. Coreq: EBME 310.

EBME 380. Design for Biomedical Engineers (3)
Design a useful product with potential commercial value. This course offers a design experience that builds on the fundamentals of Biomedical Engineering through the effective use of teams and team design. Prereq: EBME 310.

EBME 396. Special Topics in Undergraduate Biomedical Engineering I (1-18)
(Credit as arranged.) Prereq: Consent of instructor.

EBME 398. Senior Project Laboratory I (3)

EBME 399. Senior Project Laboratory II (3)

Graduate Courses

EBME 400T. Graduate Teaching I (0)
This will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the student. Students in this course may be expected to perform both contact (C) and non-contact (NC) teaching in this course sequence. Examples are: de-

velop teaching or lecture materials (NC); run recitation groups (C); provide laboratory assistance (C) or (NC); present individual lectures (C); tutor (C); prepare and grade exams/quizzes/homework (NC). Prereq: Ph.D. student in Biomedical Engineering.

EBME 402. Muscles, Biomechanics, and Control of Movement (4)
Quantitative and qualitative descriptions of the action of muscles in relation to human movement. Introduction to rigid body dynamics and dynamics of multi-link systems using Newtonian and Lagrangian approaches. Muscle models with application to control of multi-joint movement. Forward and inverse dynamics of multi-joint, muscle driven systems. Dissection, observation and recitation in the anatomy laboratory with supplemental lectures concentrating on kinesiology and muscle function. Prereq: EMAE 181 or equivalent. Cross-listed as EMAE 402.

EBME 403. Biomedical Transducers (3)
Analysis and design of transducers: optical, photo-electric, electrochemical, electrical, mechanical, electromechanical, and thermoelectric. Applications to biomedical systems. Prereq: EBME 310 and EBME 360 or consent of instructor.

EBME 405. Materials for Prosthetics and Orthotics (3)
Fundamental concepts of metallic and ceramic materials. Wear, corrosion, and failure of implants. Properties of hard tissues and joints. Characterization of biomaterials. Biocompatibility of materials. Orthopaedic and dental applications. Prereq: EBME 306.

EBME 406. Polymers in Medicine (3)
Distribution of plastic implants in the body, including history and statistics; chemical and physical characteristics of biomedical polymers, including general implant requirements, reactions of the host to implants, reactions of implants to physiological conditions, physiological and biomechanical basis for soft-tissue implants; plastic materials used in medicine and surgery; frontiers in biomedical polymers (current topics directed to the design and development of new biomedical polymers). Prereq: Consent of instructor. Cross-listed as EMAC 471.

EBME 407. Applied Neural Control (3)
Fundamental concepts related to electrical stimulation of the nervous system. Cable equation, currents in volume conductors, electrical models of axons, interaction between axons and electrical fields, tissue damage of electrical stimulation, electrochemistry of electrical stimulation, electrodes for electrical stimulation, applications to neuromuscular, sensory, and other physiological systems. Prereq: EBME 451 and EBME 409.

EBME 408. Tissue and Cellular Engineering (3)
Tissue engineering approach for augmentation or replacement of compromised tissue function in nerve, microvessels, skin and cartilage. Integrative exploration of the use of three-dimensional polymeric scaffolds and drug delivery vehicles, and gene therapy and cellular engineering for functional repair of injured tissues. Prereq: Consent of instructor.

EBME 409. Systems and Signals in Biomedical Engineering (3)
Modeling concepts (probability, kinetics, mass transport, parameter estimation); dynamic systems (nonlinear, lumped, distributed, Laplace transform, matrices, eigenvalues, linearization, stability, phase-plane); signal analysis (continuous and discrete, time and frequency domains, spectral representation, Fourier analysis, data sampling, noise analysis, filtering, aliasing); numerical methods (initial-value problems, finite differences, Fourier transforms, matrix operations, nonlinear estimation, image processing, power spectrum analysis, MATLAB implementation). Prereq: EBME 308 or equivalent.

EBME 410. Medical Imaging Fundamentals (3)
Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Prereq: EBME 308 and EBME 310 or equivalent.

EBME 411. Artificial Organs (3)
Engineering for replacement or augmentation of tissues (e.g., nerve or vascular) and organs (e.g., kidney and heart). Chemical, electrical, mechanical, materials, pathological and surgical aspects. Prereq: EBME 451 and EBME 452.

EBME 412. Biomedical Signal Processing (3)
Application of digital processing techniques to biomedical signals. Spectra and digital filters. Processing evoked responses. Electrocardiograms, electroencephalograms, and other applications. Prereq: EBME 409.

EBME 414. Laboratory Computing in Biomedical Engineering (3)
Hardware and software aspects of computer systems for laboratory application. Analog and digital interfacing. Signal conditioning and sample requirements. Computer control of laboratory instruments and data acquisition. Biomedical applications. Prereq: EBME 308 or equivalent.

EBME 416. Biomaterials in Drug Delivery (3)
Fundamental principles in design and engineering of molecular architectures of biomaterials for biomedical applications. Structure-function relationships at the molecular level. Tailoring the surface and bulk structures for applications in drug delivery, tissue engineering, and biomedical imaging. Prereq: EBME 303 or EMAC 303. Coreq: EBME 306.

EBME 417. Structure and Function of Excitable Cells (3)
Ion channels are the molecular basis of membrane excitability in all cell types, including neuronal, heart, and muscle cells. This course presents the structure and the mechanism of function of ion channels at the molecular level. It introduces the basic principles and methods in the ion channel study including the ionic basis of membrane excitability, thermodynamic and kinetic analysis of channel function, voltage clamp and patch clamp techniques, and molecular and structural biology approaches. The course will cover structure of various potassium, calcium, sodium, and chloride channels and their physiological function in neural, cardiac, and muscle cells. Exemplary channels that have been best studied will be discussed to illustrate the current understanding of the molecular mechanisms of channel gating and permeation. Prereq: Consent of instructor.

EBME 418. Electronics for Biomedical Engineering (3)
Review of electronic circuits. Analog design for biomedical electronics. Low noise, precision amplification, shielding, grounding, interfacing, and electrical safety. Electrophysiological amplifiers and biomagnetic field measurements. Prereq: EBME 308.

EBME 427. Movement Biomechanics and Rehabilitation (3)
Introduction to the basic biomechanics of human movement and applications to the design and evaluation of artificial devices intended to restore or improve movement lost due to injury or disease. Measurement techniques in movement biomechanics, including motion analysis, electromyography, and gait analysis. Design and use of upper and lower limb prostheses. Principles of neuroprostheses with applications to paralyzed upper and lower extremities. Term paper required. Prereq: Consent of instructor.

EBME 431. Physics of Imaging (3)
Description of physical principles underlying the spin behavior in MR and Fourier imaging in multi-dimensions. Introduction of conventional, fast, and chemical-shift imaging techniques. Spin echo, gradient echo, and variable flip-angle methods. Projection reconstruction and sampling theorems. Bloch equations, T1 and T2 relaxation times, RF penetration, diffusion and perfusion. Flow imaging, MR angiography, and functional brain imaging. Sequence and coil design. Prerequisite may be waived with consent of instructor. Prereq: PHYS 122 or PHYS 124 or EBME 410. Cross-listed as PHYS 431.

EBME 447. Rehabilitation for Scientists and Engineers (3)
Medical, psychological, and social issues influencing the rehabilitation of people with spinal cord injury, stroke, traumatic brain injury, and limb amputation. Epidemiology, anatomy, pathophysiology and natural history of these disorders, and the consequences of these conditions with respect to impairment, disability, handicap and quality of life. Students will directly observe the care of patients in each of these diagnostic groups throughout the full continuum of care starting from the acute medical and surgical interventions to acute and subacute rehabilitation, outpatient medical and rehabilitation management and finally to community reentry. Prereq: Consent of department.

EBME 451. Physiological Processes I (3)
Cell and molecular biology. Nerve and muscle function. Motor systems and feedback control. Autonomic system mechanisms. Brain and sensory systems.

EBME 452. Physiological Processes II (3)
Heart and vascular system. Respiratory, renal, and regulatory systems. Gastro-intestinal system and metabolism. Prereq: Consent of instructor.

EBME 460. Advanced Topics in NMR Imaging (3)
Frontier issues in understanding the practical aspects of NMR imaging. Theoretical descriptions are accompanied by specific examples of pulse sequences, and basic engineering considerations in MRI system design. Emphasis is placed on implications and trade-offs in MRI pulse sequence design from real-world versus theoretical perspectives. Prereq: EBME 431 or PHYS 431. Cross-listed as PHYS 460.

EBME 461. Biomedical Image Processing and Analysis (3)
Principles of image processing and analysis with applications to biomedical images from the nano-scale to 3D whole organ imaging. Topics include image filtering, enhancement, restoration, registration, morphological processing, and segmentation. Prereq: EBME 409 or equivalent.

EBME 478. Computational Neuroscience (3)
Computer simulation of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural circuits, as well as to cable theory, passive and active compartmental modeling, numerical integration methods, models of plasticity and learning, models of brain systems, and their relationship to artificial neural networks. Term project required. Two lectures per week. Cross-listed as EECS 478.

EBME 479. Seminar in Computational Neuroscience (3)
Readings and discussion in the recent literature on computational neuroscience, adaptive behavior, and other current topics. Cross-listed as BIOL 479.

EBME 500T. Graduate Teaching II (0)
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the student. Students in this course may be expected to perform both contact (C) and non-contact (NC) teaching in this course sequence. Examples are: develop teaching or lecture materials (NC); run recitation groups (C); provide laboratory assistance (C) or (NC); present individual lectures (C), tutor (C); prepare and grade exams/quizzes/homework (NC). Prereq: Ph.D. student in Biomedical Engineering.

EBME 501. Bioelectric Phenomena (3)
Models of excitable cells and membranes. Cardiac action potentials and propagation of excitation. Bioelectric sources, volume conductor fields, and inverse problems. Prereq: EBME 451 and EBME 409.

EBME 502. Cardiac Excitation, Rhythm, and Control (3)
Cardiac excitation: sub-cellular and cellular. Inter-cellular communication. Propagation of the cardiac electrical potential. Arrhythmias. Neural control of the heart. Vagal nerve stimulation. Neurotransmitters and neuropeptides. Prereq: EBME 501.

EBME 503. Biomolecular Forces (3)
Advanced course on the theory, measurement, and analysis of the intermolecular physical forces that dominate cell and molecular interactions in dynamic aqueous systems. The aim of this course is to provide students involved in biomaterials engineering and studies on cell and molecular interactions with (i) a quantitative and fundamental understanding of the intermolecular forces (electrostatic, van der Walls, solvation forces) that direct cell and molecular adhesion, self-assembling systems (bilayers, cell membranes) and specific and non-specific receptor-ligand binding; (ii) the ability to develop mechanistic models for surface adhesion, self-assembly, cell surface binding and signal transduction; and (iii) skills for measurement and quantitative analysis of forces (nano- to pico-Newton levels) in the "near-surface" (1-10 nm) domain by atomic force microscopy and related force measurement techniques. Prereq: EBME 405 or EBME 406, undergraduate electricity and magnetism, undergraduate physical chemistry, or consent of instructor.

EBME 504. Transport Processes of Biomedical Systems (3)
Mass and heat transport processes. Metabolic processes. Spatially lumped and distributed models of organs, tissues and cells. Numerical methods for computer simulation. Applications to cells, tissues, and organs. Prereq: EBME 409.

EBME 507. Motor System Neuroprostheses (3)
Design and implementation of neuroprostheses. Transformation of muscle action into limb movement. Musculoskeletal modeling and simulation. Control of the musculoskeletal system by neural stimulation. Prereq: Consent of instructor.

EBME 511. Nonlinear Wavefront Dynamics in Cardiac Bioelectricity (3)
Mathematical and descriptive analysis of atrial fibrillation and flutter and various types of action potential reentry. Specific aspects include phase resetting, electrical restitution and alternans generation, conduction velocity variation, spiral wave propagating patterns and stability, and propagation failure. Computer models will be used to illustrate the concepts with simulations related to the physiology, diagnosis, and treatment of abnormal cardiac rhythm. Prereq: EBME 409.

EBME 513. Biomedical Optical Diagnostics (3)
Engineering design principles of optical instrumentation for medical diagnostics. Elastic and inelastic light scattering theory and biomedical applications. Confocal and multiphoton microscopy. Light propagation and optical tomographic imaging in biological tissues. Design of minimally invasive spectroscopic diagnostics. Prereq: EBME 403 or PHYS 326 or consent.

EBME 517. Quantitative Neurophysiology (3)
This course provides a unique opportunity to gain advanced knowledge in the area of neurophysiology, neuroscience, and cellular biophysics/physiology from the quantitative point of view. The instructors are from different departments which will give students the rare opportunity to learn and understand the material from various angles. The mathematical load varies depending on the topic, however the familiarity with or willingness and ability to learn basic important mathematical concepts such as differentiation, probability, or matrices is essential. The course will start by studying the laws of physics that govern the behavior of ions in biological solutions and near the cell membrane. The next part of the course deals with the voltage-gated ion channels of the excitable cell: activity, structure, functions, and models. The third part is devoted to modeling electrical activity of a neuron. The fourth part describes the synaptic interaction between neurons, from presynaptic calcium dynamics to postsynaptic membrane and ligand-gated channels. The last part applies the acquired knowledge to understanding a neuronal network (hippocampus). Along with the lectures, the students will prepare a model of the neuron using the NEURON software. This project will be in constant development during the course, i.e., the complexity of the model will increase as long as new material is learned. Prereq: MATH 224, EBME 451, or BIOL 373/473, or permission of department.

EBME 519. Parameter Estimation for Biomedical Systems (3)
Linear and nonlinear parameter estimation of static and dynamic models. Identifiability and parameter sensitivity analysis. Statistical and optimization methods. Design of optimal experiments. Applications to cells, tissues, and organs. Prereq: EBME 409 or consent of instructor.

EBME 523. Chemical and Optical Sensors (3)
Fundamental electrical, electrochemical, and optical measurement techniques. Sensitive and selective biological membranes based on ion, enzyme, and immuno-reactions. Sensor stability and response time. Prereq: EBME 403.

EBME 550. Neuromechanics Seminar (0)
Current research in neuromechanical systems, including movement control in natural organisms, biologically inspired robots, and hybrid (artificial/natural) neural prosthetic systems. Presentations by students, faculty, and visiting scholars. Cross-listed as BIOL 550, EECS 550, and EMAE 550.

EBME 600T. Graduate Teaching III (0)
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to consist of direct student contact, but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational opportunity for the student. Students in this course may be expected to perform both contact

(C) and non-contact (NC) teaching in this course sequence. Examples are: develop teaching or lecture materials (NC); run recitation groups (C); provide laboratory assistance (C) or (NC); present individual lectures (C); tutor (C); prepare and grade exams/quizzes/homework (NC). Prereq: Ph.D. student in Biomedical Engineering.
EBME 601. Research Projects (1-18)

EBME 602. Special Topics (1-18)
Prereq: Consent of instructor.

EBME 611. BME Departmental Seminar I (0)
Required of all first-year graduate students in BME.

EBME 612. BME Departmental Seminar II (0)
Continuation of EBME Departmental Seminar I. Required of all first-year graduate students in BME.

EBME 621. BME Research Rotation I (0)
Opportunity for trainees to participate in BME research under supervision of faculty.

EBME 622. BME Research Rotation II (0)
Opportunity for trainees to participate in BME research under supervision of faculty.

EBME 651. Thesis M.S. (1-18)

EBME 701. Dissertation Ph.D. (1-18)
Ph.D. candidates only.

EBME 702. Appointed Dissertation Fellow (9)

Department of Chemical Engineering

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Peter N. Pintauro, Chair
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http://www.cwru.edu/cse/eche/

The profession of chemical engineering involves the analysis, design, operation and control of processes that convert matter and energy to more useful forms, encompassing processes at all scales from the molecular to the megascale. Traditionally, chemical engineers are responsible for the production of basic chemicals, plastics, and fibers. However, today's chemical engineers are also involved in food and fertilizer production, synthesis of electronic materials, waste recycling, and power generation. Chemical engineers also develop new materials (ceramic composites and electronic chips, for example) as well as biochemicals and pharmaceuticals. The breadth of training in engineering and the sciences gives chemical engineers a particularly wide spectrum of career opportunities. Chemical engineers work in the chemical and materials related industries, in government, and are readily accepted by graduate schools in engineering, chemistry, medicine, and law (mainly for patent law). The Bachelor of Science degree is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology.

The department offers Bachelor of Science in Engineering, Master of Science, and Doctor of Philosophy degree programs that provide preparation for work in all areas of chemical engineering. Breadth sequences in biochemical engineering, biomedical engineering, computing, electrochemical engineering, electronic materials, environmental engineering, management/entrepreneurship, polymer science, systems and control, or advanced studies provide depth and specialization for undergraduates majoring in chemical engineering. In addition, for students with a strong interest in polymer engineering, a minor in macromolecular science can be integrated with the chemical engineering curriculum. Chemical engineering undergraduates are members of the student chapter of the American Institute of Chemical Engineers (AIChE). The AIChE chapter sponsors social events, field trips to local industry, technical presentations by outside speakers, and employment counseling. Information about the AIChE can be obtained through the department, the chapter president or the chapter advisor. There are fifteen full-time faculty members, all of whom are pursuing active research programs. The research of the faculty is aimed at advanced and cutting-edge areas of chemical engineering.

Faculty

Peter N. Pintauro, Ph.D. (University of California, Los Angeles)
Professor and Department Chair
Electrochemical engineering, membrane fabrication, modeling transport in ion-exchange membrane, organic elecrochemical synthesis, fuel cells

John C. Angus, Ph.D. (University of Michigan)
Kent Hale Smith Professor of Engineering
Chemical vapor deposition of diamond, electrochemistry of diamond gallium nitride synthesis

Harihara Baskaran, Ph.D. (The Pennsylvania State University)
Assistant Professor
Transport Phenomena in Biology and Medicine

Robert V. Edwards, Ph.D. (Johns Hopkins University)
Professor
Laser anemometry, mathematical modeling, data acquisition

Donald L. Feke, Ph.D. (Princeton University)
Professor and Interim Associate Provost for Planning and Assessment.
Colloidal phenomena, dispersive mixing, fine particle processing

Nelson C. Gardner, Ph.D. (Iowa State University)
Associate Professor
High-gravity separations, sulfur removal processes

Jeffrey T. Glass, Ph.D. (University of Virginia), M.B.A. (Duke University)
Joseph S. Toot Professor of Engineering
Plasma processing and materials characterization of thin films, measurement of device properties

Howard L. Greene, Ph.D. (Cornell University)
Principal Researcher
Catalysis and reactor design

Robert E. Harris, Ph.D. (Northeastern University), M.B.A. (Case Western Reserve University)
Adjunct Professor of Engineering
Process design, process synthesis, analysis, design and simulation

Uziel Landau, Ph.D. (University of California, Berkeley)
Professor
Electrochemical engineering, modeling of electrochemical systems, electrodeposition, batteries and fuel cells

Chung-Chiun Liu, Ph.D. (Case Institute of Technology)
Wallace R. Persons Professor of Sensor Technology & Control
Electrochemical sensors, electrochemical synthesis, electrochemistry related to electronic materials

J. Adin Mann, Jr., Ph.D. (Iowa State University)
Professor
Surface phenomena, interfacial dynamics, colloid science, light scattering, biomemetics, molecular electronics

Heidi B. Martin, Ph.D. (Case Western Reserve University)
Nord Assistant Professor of Engineering
Conductive Diamond Films; Electrochemical Sensors; Chemical Modification of Surfaces for Electrochemical and Biomedical Applications; Biomaterials; Microfabrication of Sensors and Devices

Philip W. Morrison, Jr., Ph.D. (University of California, Berkeley)
Associate Professor
Materials synthesis, in-situ diagnostics of thin film and particle formation processes

Syed Qutubuddin, Ph.D. (Carnegie Mellon University)
Professor
Surfactant and polymer solutions, separations, nanoparticles, novel polymeric materials, nanocomposites

Robert F. Savinell, Ph.D. (University of Pittsburgh)
George S. Dively Professor and Dean of Engineering
Electrochemical engineering, electrochemical reactor design and simulation, electrode processes, batteries and fuel cells

Thomas A Zawodzinski, Ph.D. (State University of New York at Buffalo)
Ohio Eminent Scholar in Fuel Cells and F. Alex Nason Professor of Engineering
Fuel cells, transport and electrochemistry in energy conversion and storage devices, NMR spectroscopy and imaging, transport/ structure property relationships in polymer electrolytes, self-assembly chemistry

Undergraduate Programs

The Case School of Engineering prepares and challenges its students to take leadership positions in engineering and computer science. The increasing role of technology in virtually every facet of our culture — communications, transportation, construction, health care, the environment, and even our system of wealth distribution — makes it vital that engineering- oriented students have access to progressive and cutting-edge programs stressing the following five areas of excellence:

Bachelor of Science in Engineering Degree Major in Chemical Engineering

Freshman Year — Class-Lab-Credit Hours

Fall

Course	Class-Lab-Credit Hours
PHYS 121 General Physics I Mechanics [a]	(4-3-4)
CHEM 111 Principles of Chemistry I	(4-0-4)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(15-6-15)**

Spring

Course	Class-Lab-Credit Hours
PHYS 122 General Physics II Electricity & Magnetism [a]	(4-3-4)
ENGR 145 Chemistry of Materials	(4-0-4)
MATH 122 Calculus for Science and Engineering II	(4-0-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
Humanities/Social Science Elective	(3-0-3)
PHED 102 Physical Education Activities	(0-3-0)
Total	**(17-8-18)**

Sophomore Year

Fall

Course	Class-Lab-Credit Hours
CHEM 223/323 Organic Chemistry	(3-0-3)
MATH 223 Calculus for Science & Engineering III	(3-0-3)
ENGR 225 Thermodynamics, Fluids, Heat & Mass Transfer	(4-0-4)
ECHE 260 Introduction to Chemical Systems	(3-0-3)
ECHE 151 Chemical Engineering at Case	(1-0-0)
Humanities/Social Science or Science Elective I [b]	(3-0-3)
Total	**(17-0-16)**

Spring

Course	Class-Lab-Credit Hours
Science Elective II [b]	(3-0-3)
MATH 224 Differential Equations	(3-0-3)
STAT 313 (or STAT 312) Statistics for Experimenters	(3-0-3)
ECHE 363 Chemical Engineering Thermodynamics	(3-0-3)
Humanities/Social Science Sequence I	(3-0-3)
Total	**(15-0-15)**

Junior Year — Class-Lab-Credit Hours

Fall

Course	Class-Lab-Credit Hours
ECHE 360 Transport Phenomena for Chemical Systems	(4-0-4)
ECHE 367 Process Control	(4-0-4)
ENGR 210 Circuits & Instrumentation	(2-2-4)
CHEM 290 Advanced Chemical Laboratory Methods	(1-6-3)
Breadth Elective Sequence I [d] or Humanities/Social Science Elective	(3-0-3)
Total	**(14-8-18)**

Spring

Course	Class-Lab-Credit Hours
ECHE 361 Separation Processes	(3-0-3)
ECHE 365 Measurements Laboratory	(0-3-3)
ENGL 398N Professional Communications	(3-0-3)
ECHE 364 Chemical Reaction Processes	(3-0-3)
Humanities/Social Science Elective or Breadth Elective Sequence I [d]	(3-0-3)
Total	**(12-3-15)**

Senior Year

Fall

Course	Class-Lab-Credit Hours
ECHE 398 Process Analysis and Design	(3-0-3)
ECHE 362 Chemical Engineering Laboratory	(0-4-4)
Materials Elective [c]	(3-0-3)
Breadth Elective Sequence II [d]	(3-0-3)
Humanities/Social Science Sequence II	(3-0-3)
Total	**(12-4-16)**

Spring

Course	Class-Lab-Credit Hours
ECHE 399 Chemical Engineering Design Project	(3-0-3)
CHEM 302 Introductory Physical Chemistry II	(3-0-3)
ENGR 200 Statics and Strength of Materials	(3-0-3)
Breadth Elective Sequence III [d]	(3-0-3)
Science Elective II[b] or Humanities/Social Science	(3-0-3)
Humanities/Social Science Sequence III	(3-0-3)
Total	**(18-0-18)**

Hours required for graduation: 131-133 (depending on breadth elective sequence).

a. Selected students may be invited to take PHYS 125, 126 General Physics I, II Honors in place of PHYS 121,122.

b. Science Elective I and II. Students must take any two of the following courses—PHYS 221 General Physics III. Modern (F, Sp), CHEM 224/324 Organic Chemistry II (Sp), or BIOL 205 Chemical Biology (Sp).

c. One materials elective is required. Suggested courses include EMAC 270 Introduction to Polymer Science (F, Sp); EMAC 276 Polymer Properties and Design (F, Sp), EMSE 314 Electrical, Magnetic, Optical Properties of Materials (F); EMSE 316 Applications of Ceramic Materials; or course approved by the chemical engineering faculty.

d. A three course (9 credit hours minimum) breadth sequence (approved by the Chemical Engineering faculty). Preapproved sequences include biochemical engineering, biomedical engineering, computing, electrochemical engineering, electronic materials processing, environmental engineering, management/entrepreneurship, polymer science, systems and control, and advanced study (B.S./M.S.).

- Mastery of Fundamentals
- Creativity
- Societal Awareness
- Leadership Skills
- Professionalism

The Chemical Engineering Department expands these more general objectives as follows:

Mastery of Fundamentals

- A strong background in the fundamentals of chemistry, physics, and mathematics.
- A sound education in chemical engineering fundamentals, including mass and energy balances, separation processes, reaction engineering, thermodynamics, transport processes, and control.
- Training in computers as tools of the profession, including experience with spreadsheets, simulators, computer-aided design software, and mathematics/statistics packages.

Creativity

- Comprehensive design experiences involving problem definition, literature searching, synthesis, economics, communications, teamwork, project management, equipment choice, and safety.
- Laboratories that provide hands-on experience with equipment, design of experiments, data/statistical analysis, and reinforcement of fundamental physical concepts.
- Opportunities for individualized research experiences.

Approved Breadth Elective Sequences

Biochemical Engineering (Advisor: Dr. Qutubuddin) — Semester

BIOC 307, General Biochemistry (4) .... Fall, junior
BIOL 343, Microbiology (3) .... Spring, junior
ECHE 340, Biochemical Engineering (3) .... Spring, senior

Biomedical Engineering (Advisor: Dr. Baskaran)

EBME 201, Physiology-Biophysics I (3) .... Fall, junior
EBME 202, Physiology-Biophysics II (3) .... Spring, junior
EBME 309, Modeling of Biomedical Systems (3)
or
EBME 310, Biomedical Instrumentation (3) .... Spring, senior

Computing (Advisor: Dr. Edwards)

ECES 281 Logic Design and Computer Organization (4) Fall, junior
EECS 233, Introduction to Data Structures (4) .... Spring, junior
EECS 346, Engineering Optimization (3) .... Fall, senior

Electrochemical Engineering (Advisor: Dr. Landau)[e]

ECHE 380 Electrochemical Technology (3) .... Fall, junior
or
ECHE 381 Electrochemical Engineering (3) .... Spring, junior
ECHE 383 Chemical Engineering Applied to Microfabrication and Devices (3) .... Fall, senior
plus one additional course selected from
EMSE 314 Electronic, Magnetic, and Optical Properties of Materials (3) .... Fall, senior
EECS 309 Electromagnetic Fields I (3) .... Fall, Spring
EECS 321 Semiconductor Elec. Dev. (4) .... Spring, senior
EMSE 411, Environmental Effects on Materials Behavior (3) .... Spring, senior

Electronic Materials (Advisor: Dr. Morrison)[e]

ECHE 383 Chemical Engineering Applied to Microfabrication and Devices (3) .... Fall, junior
EECS 309 Electromagnetic Fields I (3) .... Fall, Spring
EMSE 314 Electronic, Magnetic, and Optical
Properties of Materials (3) .... Fall, senior
or
EECS 321 Semiconductor Electronic Devices (4) .... Spring, senior

Environmental Engineering (Advisor: Dr. Edwards)

ECIV 368 Environmental Engineering (3) .... Spring, junior
and two of the following:
ECIV 362 Solid and Hazardous Waste Management (3) .... Spring, junior
GEOL 436 Aquatic Chemistry (3) .... Fall, junior
ECIV 460 Environmental Remediation (3) .... Spring, senior
ECIV 464 Environmental Engineering Microbiology (3) .... Fall, senior

Management/Entrepreneurship (Advisor: Dr. Glass)

ACCT 303/403, Survey of Accounting (3) .... Fall, junior
BAFI 353, Corporation Finance (3) .... Fall, senior
plus one additional course selected from
MKMR 301, Marketing Management (3) .... Spring, junior
ENTP 311, New Venture Creation (3) .... Spring, junior
ENTP 310 Entrepreneurial Financing (3) .... Fall, senior
ENTP 295 Entrepreneurial Behavior (3) .... Fall, senior

Polymer Science (Advisor: Dr. Mann)[e]

EMAC 270, Introduction to Polymer Science (3) .... Fall, Spring
plus any two courses selected from
EMAC 276, Polymer Properties and Design (3) .... Fall, Spring
EMAC 376, Polymer Engineering (3) .... Spring, junior
EMAC 377, Polymer Processing (4) .... Spring, senior
EMAC 378, Polymer Production and Technology (3) Spring, senior

Systems and Control (Advisor: Dr. Martin)

EECS 346, Engineering Optimization (3) .... Spring, junior
ECES 281 Logic Design and Computer Organization (4) .... Fall, senior
EECS 306, Control Engineering II .... Spring, senior
or
ECHE 463, Model Based Control (3)

Advanced Study Sequence (Advisor: Dr. Morrison)[f]

ECHE 460, Thermodynamics (3)
or
ECHE 475, Chemical Engineering Analysis (3) .... Fall, senior
ECHE 651 Master's Thesis (3) .... Fall, senior
ECHE 651 Master's Thesis (3) .... Spring, senior

e. In these sequences, coordinate your choice of breadth electives with your choice for the Materials Elective.
f. This sequence is designed for students entering the five-year B.S./M.S. program. Students taking this sequence should rearrange the scheduling of the elective sequence and humanities/social science courses in the junior and senior years to accommodate these courses.

Societal Awareness

- Understanding of the technological and human resource needs of industry, government, and society.
- A sufficiently broad education to understand the impact of engineering on society
- Opportunities to explore other cultures and learning environments through a Junior Year in Edinburgh program and a summer Chemical Engineering Laboratory course at University College London.

Leadership Skills

- Multiple and integrated opportunities to develop written and oral communication skills.
- Develop specialized knowledge in a series of breadth electives, such as biomedical engineering, biochemical engineering, computing, electrochemical engineering, electronic materials, environmental engineering, management/entrepreneurship, polymer science, control, or research.
- Leadership roles in group-based course activities encouraging a "can do" positive attitude and developing skills in teamwork.

Professionalism

- A commitment to excellence and unquestioned integrity.
- An understanding of safety and ethical issues, and the environmental consequences of the practice of chemical engineering.
- An atmosphere of self-instruction as a preparation for lifelong learning.
- Opportunities for professional development through the Cooperative Education Program.

Elective Sequences

A distinctive feature of the chemical engineering program is the three-course breadth elective sequence taken during the junior and senior years that permits a student to major in chemical engineering and, at the same time, pursue an interest in a related field. Nine elective sequences have standing departmental approval: biochemical engineering, biomedical engineering, computing, electrochemical engineering, electronic materials, environmental engineering, management/entrepreneurship, polymer science, and systems and control. There is also an advanced study sequence for combined B.S./M.S. students.

Minor in Polymer Engineering

For students wanting to pursue an interest in polymers, but major in chemical engineering, two five-course minor sequences, Polymer Processing and Characterization, and Polymer Production are available.

Polymer Processing and Characterization

EMAC 270, Introduction to Polymer Science (F, Sp)
EMAC 376, Polymer Engineering (F, Sp)
EMAC 377, Polymer Processing (F)
EMAC 372, Polymer Processing and Testing Laboratory (Sp)
EMAC 575, Polymer Rheology

Polymer Production

EMAC 270, Introduction to Polymer Science (F,Sp)
EMAC 272, Polymer Analysis Laboratory (Sp)
EMAC 276, Polymer Properties and Design (Sp)
EMAC 378, Polymer Production and Technology (Sp)
EMAC 398, Polymer Sci. & Engr. Project (F, Sp)

Minor Sequence in Chemical Engineering

A minor sequence in chemical engineering is available for students majoring in engineering, chemistry, or physics. A minimum of 15 credits must be completed, and must include
ECHE 260 Introduction to Chemical Systems
ENGR 225 Thermodynamics, Fluid Mechanics, Heat and Mass Transfer (F,Sp)
ECHE 360 Transport Phenomena for Chemical Systems (F)
and any two of the following
ECHE 361 Separation Processes (Sp)
ECHE 363 Thermodynamics of Chemical Systems (Sp)
ECHE 364 Chemical Reaction Processes (Sp)
ECHE 365 Measurements Laboratory (Sp)
ECHE 367 Process Control (F)

Five-Year Combined B.S./M.S. Program

This program offers outstanding undergraduate students the opportunity to obtain an M.S. degree, with a thesis, in one additional year of study beyond the B.S. degree. (Normally, it takes 2 years beyond the B.S. to earn an M.S. degree.) In this program, an undergraduate student can take up to nine hours of graduate credit that simultaneously satisfies undergraduate requirements. Typically, students in this program start their research leading to the M.S. thesis in the fall semester of the senior year. The department endeavors to support such students through the following summer and academic year at the normal stipend for entering graduate students. The B.S. degree is awarded at the completion of the senior year. Application for admission to the five year B.S./M.S. program is made after completion of five semesters of course work. Minimum requirements are a 3.2 grade point average and the recommendation of the department.

Five-and-a Half Year Cooperative B.S./ M.S. Program

The cooperative bachelor's/master's program enables outstanding students who are enrolled in the cooperative program to earn an M.S. in one semester beyond the B.S. degree. Students complete six credits of a graduate project (ECHE 660) during the second co-op period and follow an Advanced Study elective sequence. The courses ECHE 460, ECHE 461, and an agreed-upon mathematics course are used to satisfy both graduate and undergraduate requirements. At the end of the fifth year, the student receives the B.S. degree. Upon completion of an additional 12 credits of graduate work the following semester, the student receives the M.S. degree (non-thesis). Application for admission to the five-and a-half-year co-op B.S./M.S. program is made during the second semester of the junior year (this semester is taken in the fall of the fourth year). Minimum requirements are a 3.2 grade point average, good performance in the previous co-op assignment, and the recommendation of the department.

Graduate Programs

Master of Science Program

Each M.S. candidate must complete a minimum of 27 hours of graduate-level credits. These credits can be distributed in one of two ways.

Plan A.

Students electing Plan A take 19 hours of graduate-level course work (six courses plus ECHE 401, Chemical Engineering Communications) and complete at least 9 credit hours of M.S. thesis research.

Plan B.

Part-time students, and those in the 5-1/2-year B.S./M.S. cooperative program, may opt for Plan B, which requires completion of 24 credit hours (eight courses) of approved graduate course work and a 3 credit hour project replacing the M.S. thesis. In special cases, a student may be permitted to complete a 6 credit project. In this case only seven courses will be required.

All M.S. students are required to take the following courses: ECHE 460, Thermodynamics of Chemical Systems (3) ; ECHE 461, Transport Phenomena (3) ; ECHE 462, Chemical Reaction Engineering (3) ; and ECHE 475, Chemical Engineering Analysis (3) or an equivalent graduate-level math course. The other courses should be technical graduate-level courses selected after consultation with the advisor. In special circumstances, e.g., students have taken a similar or complementary course at another university, one of the required courses may be waived from the Program of Study. All full-time M.S. students are expected to do some teaching as part of their education. Also, at various points during their thesis research, students will be required to present seminars and reports on their progress.

Master of Engineering Program

The Department of Chemical Engineering also participates in the practice-oriented Master of Engineering program offered by the Case School of Engineering. In this program, students complete a core program. The Department of Chemical Engineering participates in the Chemical and Materials Processing and Synthesis sequence.

Doctor of Philosophy Program

The degree of Doctor of Philosophy is awarded in recognition of deep and detailed knowledge of chemical engineering and comprehensive understanding of related subjects together with a demonstration of the ability to perform independent investigations, to suggest new areas for research, and to communicate results in an acceptable manner. The minimum course requirements for the Ph.D. degree in chemical engineering are as follows:

Depth Courses

All programs of study must include ECHE 401, Chemical Engineering Communications (1), ECHE 460, Thermodynamics (3), ECHE 461, Transport Phenomena (3), and ECHE 462, Chemical Reaction Engineering (3), plus a minimum of three other chemical engineering courses.

Breadth and Basic Science Courses

A minimum of six courses outside the department must be taken. These can be chosen from other engineering departments and the departments of mathematics, chemistry, physics, biology, and geological sciences. A minimum of two elective courses must be in mathematics.

Comments on Ph.D. Guidelines

The department anticipates that from time to time special cases will arise which are exceptions to the above guidelines, e.g., a student may have taken a graduate-level thermodynamics course at another school. In these cases, the student must attach a statement to the program of study justifying the departure from the guidelines. It should be noted that the above guidelines are a minimum requirement. Only in rare circumstances will programs of study be approved with only 12 courses (36 credit hours). A total of 15 courses (45 credit hours) is typical for the Ph.D. degree. It is expected that the elective courses will form a coherent whole with a concentration in one area, e.g., systems, polymers, surface science, etc., rather than a smattering of introductory courses in many diverse subjects. All programs are chosen with the approval of the student's faculty advisor.

Other Requirements for the Ph.D. Degree

Students who wish to enter the Ph.D. program must pass a general examination covering material through the beginning graduate level courses. A thesis proposal and an independently generated proposal are also required. All Ph.D. students must satisfy the residency requirements of the university and the Case School of Engineering. Some teaching is also required. In addition, at various points in the course of the dissertation research, students will be required to prepare reports and seminars on their work, and defend their dissertation. The Chemical Engineering Graduate Student Handbook contains a more detailed description of the department's Ph.D. requirements and a time schedule for their completion.

Current Research Topics

The research ini the department is sponsored by a variety of state and federal agencies, by private industry, and by foundations. current active rsarch topic include:

Electrochemical Engineering

- Fuel cell technology
- Membrane synthesis and modeling
- Bipolar discrete electrodes
- Microelectronic materials, fabrication and processing
- Solid-state electrochemical and biomedical sensors
- Modeling of electrochemical systems, batteries and fuel cells
- Microfabrication by electrodeposition
- Electrodeposition of semiconductors and alloys
- Diamond electrodes
- Corrosion protection

Biochemical Engineering

- Biotransport
- Design of microvascular flow analogs
- Predictive methods for cancer metastasis potential
- Sensors for neurologically active molecules
- Biotelemetric micro systems

Advanced Materials Processing

- Combustion and plasma synthesis of thin films
- Low pressure synthesis of diamond
- Synthesis of bulk gallium nitride
- Aerosol synthesis
- Fine particle processing strategies
- Colloidal route to nanoparticles
- Monolayers and ultrathin films
- Computation of phase diagrams
- Langmuir Blodgett multilayers
- Polymeric surfactants and polymer-substrate interactions
- Polymer nanocomposites

Process Engineering

- Acoustic separations
- Process monitoring
- Separation using microemulsions
- Carbon dioxide sequestration
- Process intensification using centrifugal fields
- Spreading phenomena
- Rheology of emulsions and coatings, microemulsions and micelles

Facilities

The department is housed in the Albert W. Smith Building on the Case Quadrangle. Professor Smith was chair of industrial chemistry at Case from 1911 to 1927. Under his leadership a separate course of study in chemical engineering was introduced at Case in 1913. Professor Smith was also a close associate of Herbert Dow, the Case alumnus who founded Dow Chemical in 1890 with the help and support of Professor Smith. The Albert W. Smith Chemical Engineering Building contains two classrooms, one designed for computer and television instruction; the undergraduate Unit Operations Laboratory; a high bay area for process-related research; reinforced concrete, vertically vented chamber for hazardous and high-pressure research; a constant temperature and humidity room; an instrument room; and the normal complement of offices and research laboratories. The department has unusually strong facilities for electrochemical and fuel cell research, for microfabrication, and for chemical vapor deposition and thin film synthesis. In addition, a full range of biochemical, analytical and materials characterization instrumentation is available in the Case School of Engineering. Analytical instrumentation is available within the Department of Chemical Engineering, the Department of Chemistry, and the Materials Research Laboratory.

Chemical Engineering (ECHE)

Undergraduate Courses

ECHE C100. Co-op Seminar I for Chemical Engineering (1)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 001.

ECHE C200. Co-op Seminar II for Chemical Engineering (2)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 002 and ECHE C100.

ECHE 151. Introduction to Chemical Engineering at Case (0)
Introduction to the Chemical Engineering Department and its activities: faculty and faculty research areas, breadth elective sequences, cooperative education, Summer Lab in London, Junior Year in Edinburgh, industrial employment opportunities, non-traditional employment opportunities. Required of Chemical Engineering students before their junior year.

ECHE 250. Honors Research I (1-3)
A special program which affords students the opportunity to conduct research under the guidance of one of the faculty. At the end of the first semester of the sophomore year, students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. Subject to the availability of funds, the faculty employs students through the summers of their sophomore and junior years, as members of their research teams.

ECHE 251. Honors Research II (1-3)
(See ECHE 250.) Prereq: ECHE 250.

ECHE 260. Introduction to Chemical Systems (3)
Material and energy balances. Conservation principles and the elementary laws of physical chemistry applied to chemical processes. Developing skills in quantitative formulation and solution of word problems.

ECHE 340. Biochemical Engineering (3)
Chemical engineering principles applied to biological and biochemical systems and related processes. Microbiology and biochemistry linked with transport phenomena, kinetics, reactor design and analysis, and separations. Specific examples of microbial and enzyme processes of industrial significance. Prereq: BIOC 307 and BIOL 343 and ECHE 364.

ECHE 360. Transport Phenomena for Chemical Systems (4)
Viscous and turbulent fluid flow; heat and mass transport. Microscopic and macroscopic transport of mass, momentum, and energy including conduction and convection as well as interfacial and radiative heat transport. Design of piping networks, pumps, packed/fluidized beds, and heat exchangers. Diffusion and interfacial mass transfer. Heat and mass transfer analogies. Vector/tensor analysis and dimensional analysis used throughout. Prereq: MATH 223 and ENGR 225.

ECHE 361. Separation Processes (3)
Analysis and design of separation processes involving distillation, extraction, absorption, adsorption, and membrane processes. Design problems and the physical and chemical processes involved in separation. Equilibrium stage, degrees of freedom in design, graphical and analytical design techniques, efficiency and capacity of separation processes. Prereq: ECHE 260 and ECHE 363.

ECHE 362. Chemical Engineering Laboratory (4)
Experiments in the operation of separation and reaction equipment, including design of experiments, technical analysis, and economic analysis. Experiments cover distillation, liquid-liquid extraction, heat transfer, fluidized beds, control, membrane separations, and chemical and electrochemical reactors. Prereq: ECHE 360, ECHE 361, ECHE 363, and ECHE 364.

ECHE 362L. Chemical Engineering Laboratory in London (4)
A version of ECHE 362 taught during the summer at University College of London. Prereq: ECHE 360, ECHE 363, and ECHE 364.

ECHE 363. Thermodynamics of Chemical Systems (3)
First law, second law, phase equilibria, phase rule, chemical reaction equilibria, and applications to engineering problems. Thermodynamic properties of real substances, with emphasis on solutions. Thermodynamic analysis of processes including chemical reactions. Prereq: ECHE 260 and ENGR 225. Coreq: MATH 224.

ECHE 364. Chemical Reaction Processes (3)
Design of homogeneous and heterogeneous chemical reactor systems. Relationships between type of reaction and choice of reactor. Methods of obtaining and analyzing kinetic data. Relationship between mechanism and reaction rate and brief introduction to catalysis. Prereq: ECHE 360.

ECHE 365. Measurements Laboratory (3)
Laboratory introduction to measurement techniques in engineering. Matching measurements to approximate and exact physical models is stressed. Extraction of physical parameters and estimation of the errors in the parameter estimates is an important part of the course. Examples cover steady and unsteady state heat transfer, momentum transfer, and the first law of thermodynamics. Prereq: ECHE 360.

ECHE 367. Process Control (4)
Feedback control of chemical processes. The course involves extensive use of computer software and all exams are taken using the computer. Topics include: analysis of linear dynamical systems using Laplace transforms, derivation of unsteady state mathematical models of simple chemical processes, dynamic simulation of linear and nonlinear models, design of PID controllers by model inverse methods, tuning of controller to accommodate process model uncertainty, two degrees of freedom controllers, feed-forward and cascade control. Prereq: MATH 224.

ECHE 380. Electrochemical Technology (3)
Fundamentals of modern electrochemical technology and the engineering principles involved. Basics of classical electrochemistry; thermodynamics and kinetics. Engineering aspects of transport phenomena, scaling, and design as applied to electrochemical industries. Practical examples from metal finishing, batteries and fuel cells, and the electrolytic industries. Prereq: ECHE 260.

ECHE 381. Electrochemical Engineering (3)
Engineering aspects of electrochemical processes including current and potential distribution, mass transport and fluid mechanical effects. Examples from industrial processes including electroplating, industrial electrolysis, corrosion, and batteries. Prereq: ECHE 260 or permission of instructor. Cross-listed as ECHE 480.

ECHE 383. Chemical Engineering Applied to Microfabrication and Devices (3)
Silicon based microfabrication and micromachining require many chemical engineering technologies. Microfabricated devices such as sensors are also directly related to chemical engineering. The applications of chemical engineering principles to microfabrication and micromachining are introduced. Oxidation processing, chemical vapor deposition, etching and patterning techniques, electroplating and other technologies are discussed.

ECHE 398. Process Analysis and Design (3)
Economic analysis and cost estimation of chemical processes. Equipment and materials selection in the chemical process industry. Scale consideration, plant layout and plant site selection. Process analysis, heuristics and optimization. Environmental and plant safety issues. Prereq: ECHE 360, ECHE 361, ECHE 363, and ECHE 364.

ECHE 399. Chemical Engineering Design Project (3)
A capstone course for chemical engineering seniors. Uses material taught in previous and concurrent courses in an integrated fashion to solve chemical process design problems. Emphasis is placed on applying modern computer based design tools. Practicality, economics, scheduling, decision making with uncertainty, and proposal and report preparation. Numerous small exercises and one comprehensive process design project done by the class. Prereq: ECHE 398.

Graduate Courses

ECHE 400T. Graduate Teaching I (0)
All Ph.D. students are required to take this course. The experience includes elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Prereq: Entering Ph.D. student in Chemical Engineering.

ECHE 401. Chemical Engineering Communications (1)
Introductory course in communication for Chemical Engineering graduate students: preparation of first proposal for thesis, preparation of technical reports and scientific papers, literature sources, reviewing proposals, and manuscripts for professional journals, and making effective technical presentations.

ECHE 460. Thermodynamics of Chemical Systems (3)
Phase equilibria, phase rule, chemical reaction equilibria in homogeneous and heterogeneous systems, ideal and non-ideal behavior of fluids and solutions, thermodynamic analysis of closed and open chemical systems with applications. Prereq: ECHE 363.

ECHE 461. Transport Phenomena (3)
Mechanisms of heat, mass, and momentum transport on both molecular and continuum basis. Generalized equations of transport. Techniques of solution for boundary value problems in systems of conduction, diffusion, and laminar flow. Boundary layer and turbulent systems. Prereq: ECHE 360.

ECHE 462. Chemical Reaction Engineering (3)
Steady and unsteady state mathematical modeling of chemical reactors from conservation principles. Interrelation of reaction kinetics, mass and heat transfer, flow phenomena. Catalytic and chemical vapor deposition reactors. Determination of kinetic parameters. Includes catalytic and chemical vapor deposition reactors. Prereq: ECHE 364.

ECHE 463. Techniques of Model-based Control (3)
Strategies of process control centered around the use of process models in the control system. Topics include single loop, feedforward, cascade and multivariable internal model control. Tuning controllers to accommodate process uncertainty. Treatment of control effort and output constraints in model predictive control and modular-multivariable control. Prereq: ECHE 367. Cross-listed as EECS 463.

ECHE 464. Surfaces and Adsorption (3)
Thermodynamics of interfaces, nature of interactions across phase boundaries, capillary wetting properties of adsorbed films, friction and lubrication, flotation, detergency, the surface of solids, relation of bulk to surface properties of materials, non-catalytic surface reaction. Prereq: CHEM 335 or equivalent.

ECHE 465. Catalysis (3)
Nature of catalytic processes, chemisorption, catalyst pore structure and surface area, role of lattice imperfections, geometric and electronic factors, dynamics and selectivity, typical reaction mechanisms, design of catalytic reactors.

ECHE 466. Colloid Science (3)
Stochastic processes and interparticle forces in colloidal dispersions. DLVO theory, stability criteria, and coagulation kinetics. Electrokinetic phenomena. Applications to electrophoresis, filtration, floatation, sedimentation, and suspension rheology. Investigation of suspensions, emulsions, gels, and association colloids. Prereq: CHEM 335 or equivalent.

ECHE 467. Statistical Theories of Materials (3)
The classic ensembles of statistical thermodynamics will be developed and used to compute molecular properties, properties of fluids, liquids and solids. Molecular dynamics for computing properties will be explained and illustrated. Monte Carlo techniques will be discussed. An introduction to the theory of transport coefficients will be given. Applications will include interfacial systems, polymer systems and electrochemical systems.

ECHE 469. Chemical Engineering Seminar (0)
Distinguished outside speakers present current research in various topics of chemical engineering science. Graduate students also present technical papers based on thesis research.

ECHE 474. Biotransport Processes
Biofluid dynamics in physiological and pathological systems. Heat and mass transfer in tissues and organs: energy metabolism and temperature regulation, oxygen and carbon dioxide transport. Cell and tissue engineering. Receptor-mediated processes: cell adhesion, proliferation and migration. Bio-MEMS: microfabrication methods in bioengineering.

ECHE 475. Chemical Engineering Analysis (3)
Mathematical analysis of problems in transport processes, chemical kinetics, and control systems. Examines vector spaces and matrices and their relation to differential transforms, series techniques (Fourier, Bessel functions, Legendre polynomials). Prereq: MATH 224.

ECHE 480. Electrochemical Engineering (3)
Engineering aspects of electrochemical processes including current and potential distribution, mass transport and fluid mechanical effects. Examples from industrial processes including electroplating, industrial electrolysis, corrosion, and batteries. Prereq: ECHE 260 or permission of instructor. Cross-listed as ECHE 381.

ECHE 483. Chemical Engineering Applied to Microfabrication and Devices (3)
Silicon based microfabrication and micromachining require many chemical engineering technologies. Microfabricated devices such as sensors are also directly related to chemical engineering. The applications of chemical engineering principles to microfabrication and micromachining are introduced. Oxidation processing, chemical vapor deposition, etching and patterning techniques, electroplating and other technologies are discussed. Graduate students will submit an additional final projection some technical aspect of microfabrication technology or devices. Prereq: ECHE 363 and ECHE 371.

ECHE 500T. Graduate Teaching II (0)
All Ph.D. students are required to take this course. The experience will include elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assistance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Prereq: Ph.D. student in Chemical Engineering.

ECHE 560. Advanced Chemical Thermodynamics (3)
Chemical and phase equilibria in complex, multi-phase systems. Review of relevant theory. Sources of thermochemical data, methods of calculation and applications to phase diagrams, materials synthesis, electrochemistry, corrosion, water chemistry, silicon processing, chemical vapor deposition. Prereq: ECHE 460 or equivalent.

ECHE 561. Advanced Transport Phenomena (3)
(Extension of ECHE 461.) In-depth examination of methods of solving transport problems. Emphasis on coupled systems where two or more transport processes interact. Prereq: ECHE 461.

ECHE 575. Advanced Chemical Engineering Analysis (3)
Advanced analytical techniques for exact and approximate engineering analysis. Scale analysis and recursion techniques; asymptotic analysis of ordinary differential equations (regular and singular perturbations, WKB theory); approximation of integrals; method of characteristics, shocks; application to heat, mass and momentum transfer. Prereq: ECHE 475.

ECHE 600T. Graduate Teaching III (0)
All Ph.D. students are required to take this course. The experience will include elements from the following tasks: development of teaching or lecture materials, teaching recitation groups, providing laboratory assis-

tance, tutoring, exam/quiz/homework preparation and grading, mentoring students. Prereq: Ph.D. student in Chemical Engineering.

ECHE 601. Independent Study (1-18)

ECHE 651. Thesis M.S. (1-18)

ECHE 660. Special Problems (1-18)

ECHE 701. Dissertation Ph.D. (1-18)

ECHE 702. Appointed Dissertation Fellow (9)

Department of Civil Engineering

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Programs in Environmental, Geotechnical, and Structural Engineering, Construction Engineering and Management and Engineering Mechanics

Civil engineering is concerned with the environment and with the planning, design, and construction of facilities for meeting the needs of modern society. Examples of such facilities are transportation systems, schools and office buildings, bridges, dams, land reclamation projects, water treatment and distribution systems, commercial buildings, and industrial plants. Civil engineers can choose from a broad spectrum of opportunities in industry and consulting practice as well as research and development in firms in which civil engineers often participate as owners or partners. Employment can be found among a wide variety of industrial, governmental, construction, and private consulting organizations. There is a large demand for civil engineers nationally. The program at Case Western Reserve University is built around small classes, good faculty-student relationships and advising, and a program flexible enough to meet students' personal career aims.

The Department of Civil Engineering of the Case School of Engineering offers an accredited Bachelor of Science degree in Civil Engineering with courses in almost all the traditional civil engineering subjects. The graduate program offers the Master of Science and Doctor of Philosophy degrees in structures, engineering mechanics, geotechnical and environmental engineering. A cooperative education program involving participating engineering firms is available for both undergraduate and graduate students.

An active research program gives the students opportunities to participate in projects related to design, analysis, and testing. Projects are in areas such as computational mechanics, probabilistic design, bridges, dynamics and wind engineering, response of concrete and steel structures, fracture mechanics, static and dynamic behavior of soils, earthquake engineering, subsurface and ex-situ remediation, colloid behavior in environmental systems, and contaminated sediment dynamics.

Mission Statement

Our mission is to prepare students for leadership roles in civil and environmental engineering. The department will provide facilities and research expertise to advance the state of the civil engineering profession within the mission of the Case School of Engineering. Students will be taught to address problems building on solid technical foundations while taking advantage of advanced technologies. Our graduates will adhere to high technical and ethical standards, in service to the public. Graduates will be prepared for the pursuit of advanced learning in civil engineering and related fields, as well as for the practice of civil and environmental engineering at the highest professional levels.

Faculty

Robert L. Mullen, Ph.D. (Northwestern University), P.E.
Professor and Chair
Computational mechanics; finite elements; boundary elements

Roberto Ballarini, Ph.D. (Northwestern University)
Professor
Mechanics of solids, including civil engineering materials, advanced composites, microelectromechanical systems, mollusks, and bone. Mechanics education.

J. Ludwig Figueroa, Ph.D. (University of Illinois, Urbana-Champaign), P.E.
Professor
Dynamic behavior of soils and transportation materials, pavement evaluation; computer application to geotechnical and transportation materials engineering

Dario A. Gasparini, Ph.D. (Massachusetts Institute of Technology), P.E.
Professor
Structures; wind and earthquake engineering; applied random processes

Arthur A. Huckelbridge, D.Eng. (University of California, Berkeley), P.E.
Associate Professor
Structures; design and dynamics; earthquake engineering, bridge engineering

Aaron A. Jennings, Ph.D. (University of Massachusetts), P.E.
Professor
Environmental and geo-environmental engineering, groundwater contamination, hazardous waste management, uncertainty analysis for environmental models

Vassilis P. Panoskaltsis, Ph.D. (University of California, Berkeley)
Associate Professor
Constitutive modeling of civil engineering materials; thermomechanics of solids; viscoelasticity, plasticity, damage mechanics; fatigue; computational mechanics

Adel S. Saada, Ph.D. (Princeton University), P.E.
Frank H. Neff Professor
Mechanics of materials; static and dynamic mechanical behavior of soils; foundation engineering

Karen L. Skubal, Ph.D. (University of Michigan)
Assistant Professor
Bioremediation of recalcitrant organic pollutants in soils and aquifers; environmental microbiology.

Xiangwu Zeng, Ph.D. (Cambridge University)
Associate Professor
Geotechnical earthquake engineering; centrifuge modeling; foundation vibration.

Secondary Faculty

Thomas P. Kicher, Ph.D. (Case Institute of Technology)
Professor of Mechanical and Aerospace Engineering
Elastic stability; plates and shells; composite materials; dynamics and optimization

Undergraduate Program

The faculty of the civil engineering department believe very strongly that undergraduate education should prepare students to be productive engineers upon receiving the degree. For this reason, particular emphasis in undergraduate teaching is placed on the application of engineering principles to the solution of problems. After completing a broad civil engineering core program undergraduate students must choose an elective sequence in one of the areas of civil engineering of particular interest, such as structural, geotechnical, environmental, construction management or engineering mechanics.

In order to provide undergraduates with experience in industry, the department attempts to arrange summer jobs for the three summers between their semesters at Case Western Reserve University. By working for organizations in all areas of design and construction, students can gain an invaluable knowledge of the way the industry functions. This experience lets them gain more from their education and makes them more attractive to prospective employers upon graduation.

A cooperative education program is also available, which requires the student to spend two full semesters working full-time in an engineering capacity with a contractor, consulting engineer, architect, or materials supplier during the course of his or her education. The aim of the program is to enable students to make their education more meaningful by gaining familiarity with the industry they will work in after graduation and to help students finance their education.

The accredited undergraduate program in civil engineering at Case Western Reserve University has been designed so that the student chooses a sequence of four (4) or more approved elective courses. The sequence is intended to give students the chance to pursue in some depth a particular area related to their careers as civil engineers. Samples of courses from which elective sequences could be chosen follow the civil engineering curriculum in this bulletin. In addition, the students are required to do a senior project in their area of interest.

Students enrolled in other majors may elect to pursue a minor in civil engineering or in environmental engineering. A minimum of 15 credit hours is required. The approval of the department is required.

Most classes at Case Western Reserve University are small, and the student has close contact with the faculty. Students have an opportunity to gain practical experience as well as earn a supplemental income by assisting faculty members on consulting work during vacation periods.

Educational Objectives

Mastery of Fundamentals:

- Graduates will master the fundamentals of mathematics and the sciences that form the basis for engineering.

Bachelor of Science in Engineering Degree Major in Civil Engineering

Freshman Year — Class-Lab-Credit Hours

Fall

Open elective or Humanities/Social Science	(3-0-3)[a]
CHEM 111 Principles of Chemistry for Engineers	(4-0-4)
CMPS 131 Elementary Computer Programming	(2-2-3)
ENGL 150 Expository Writing	(3-0-3)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(16-5-17)**

Spring

Open elective or Humanities/Social Science	(3-0-3)[a]
ENGR 145 Chemistry of Materials	(4-0-4)
MATH 122 Calculus for Science and Engineering II	(4-0-4)
PHED 102 Physical Education Activities	(0-3-0)
PHYS 121 General Physics I	(4-0-4)
Total	**(15-3-15)**

Sophomore Year

Fall

Humanities or Social Science Sequence I	(3-0-3)
ECIV 160 Surveying and Computer Graphics	(2-3-3)
EECS 251 Numerical Methods I	(2-2-3)[c]
ENGR 200 Statics and Strength of Materials	(3-0-3)
MATH 223 Calculus for Science and Engineering III	(3-0-3)
PHYS 122 General Physics II	(4-0-4)
Total	**(17-5-19)**

Spring

Humanities or Social Science Sequence II	(3-0-3)
ECIV 310 Strength of Materials	(3-0-3)
EMAE 181 Dynamics	(3-0-3)
ENGR 210 Introduction to Circuits and Instrumentation	(3-2-4)
MATH 224 Elementary Differential Equations	(3-0-3)
Total	**(15-2-16)**

Junior Year — Class-Lab-Credit Hours

Fall

Humanities or Social Science Sequence III	(3-0-3)
ECIV 211 Civil Engineering Materials	(1-3-3)
ECIV 320 Structural Analysis I	(3-0-3)
ENGL 398N Professional Communications	(3-0-3)
ENGR 225 Thermodynamics, Fluid Mechanics, Heat and Mass Transfer	(3-0-4)
Total	**(13-3-16)**

Spring

ECIV 322 Structural Design I	(2-2-3)
ECIV 330 Soil Mechanics	(3-2-4)
ECIV 351 Engineering Hydraulics and Hydrology	(3-0-3)
ECIV 368 Environmental Engineering	(2-2-3)
Approved Elective	(3-0-3)[b]
Total	**(13-6-16)**

Senior Year

Fall

Humanities or Social Science Elective	(3-0-3)
ECIV 340 Construction Management	(3-0-3)
ECIV 398 Civil Engineering Senior Project	(0-6-3)
Approved Elective	(3-0-3)[b]
Approved Elective	(3-0-3)[b]
Total	**(12-6-15)**

Spring

Humanities or Social Science Elective	(3-0-3)
ECIV 360 Civil Engineering Systems	(3-2-3)
PHYS 221 or approved Natural Sciences substitute	(3-0-3)
Approved Elective	(3-0-3)[b]
Open Elective	(3-0-3)
Total	**(15-2-15)**

Hours required for graduation: 129

a. One of these courses must be a humanities/social science course.
b. Must be part of an approved sequence.
c. May substitute EMAE 250.

Samples of Courses from Which Elective Sequences Could Be Chosen

The approved electives constitute a sequence of four courses in one of the major areas of civil engineering. They are chosen by the student to coincide with his or her interests.

Structural Engineering

ECIV 321, Structural Analysis II (3)
ECIV 323, Structural Design II (3)
ECIV 405, Solid Mechanics I (3)
ECIV 406, Constitutive Modeling Theories (3)
ECIV 411, Applied Elasticity (3)
ECIV 415, Structural Modeling and Experimental Methods (3)
ECIV 420, Finite Element Analysis (3)
ECIV 421, Advanced Reinforced Concrete Design (3)
ECIV 422, Advanced Structural Steel Design (3)
ECIV 423, Prestressed Concrete Design (3)
ECIV 430, Foundation Engineering (3)

Geotechnical Engineering

ECIV 323, Structural Design II (3)
ECIV 405, Solid Mechanics I (3)
ECIV 406, Constitutive Modeling Theories (3)
ECIV 411, Applied Elasticity (3)
ECIV 420, Finite Element Analysis (3)
ECIV 430, Foundation Engineering (3)
ECIV 431, Special Topics in Geotechnical Engineering (3)
ECIV 433, Soil Dynamics (3)
GEOL 110, 119, Physical Geology (3), Lab (1)
GEOL 330, Geophysical Field Methods (4)

Engineering Mechanics

ECIV 405, Solid Mechanics I (3)
ECIV 406, Constitutive Modeling Theories (3)
ECIV 411, Applied Elasticity (3)
ECIV 420, Finite Element Analysis (3)
ECIV 433, Soil Dynamics (3)
EMAE 372, Relation of Materials to Design (3)

Environmental Engineering

ECIV 361, Water Resources Engineering (3)
ECIV 362, Solid and Hazardous Waste Management (3)
ECIV 370, Unit Operations and Processes in Environ. Engineering (3)
ECIV 450, Environmental Engineering Chemistry (3)
ECIV 460, Environmental Remediation (3)
GEOL 220, Environmental Geology (3)
GEOL 321, Hydrogeology (3)

Construction Engineering & Management

Two of the four elective courses must be from within civil engineering.

ACCT 303, Survey of Accounting (3)
BAFI 355, Corporation Finance (3)
BLAW 329, Law & Management(3)
ECIV 341, Construction Scheduling and Estimating (3)
ECIV 430, Foundation Engineering (3)
ECON 361, Managerial Economics (3)
LHRP 251, Industrial Relations & Administrative Practices (3)
LHRP 311, Labor Problems (3)

Minor in Civil Engineering

Students enrolled in other majors may elect to pursue a minor in Civil Engineering. A minimum of 15 credit hours is required, as follows:

Required Course

ENGR 200, Statics and Strength of Materials (3)

Select a minimum of 12 credit hours from one of the following areas (approval of the department is required):

Solid Mechanics

ECIV 310, Strength of Materials (3)
ECIV 405, Solid Mechanics I (3)
ECIV 406, Constitutive Modeling Theories (3)
ECIV 411, Applied Elasticity (3)
ECIV 415, Structural Modeling & Experimental Methods (3)
ECIV 420, Finite Element Analysis (3)

Structural & Geotechnical Engineering

ECIV 320, Structural Analysis I (3)
ECIV 321, Structural Analysis II (3)
ECIV 322, Structural Design I (3)
ECIV 323, Structural Design II (3)
ECIV 330, Soil Mechanics (4)
ECIV 430, Foundation Engineering (3)
ECIV 433, Soil Dynamics (3)

Construction Engineering and Management

Two of the courses must be
ECIV 340, Construction Management (3)
ECIV 341, Construction Scheduling and Estimating (3)
Two or more courses chosen from ACCT 303, BAFI 355, BLAW 329, ECON 361, LHRP 251, LHRP 311.

Minor in Environmental Engineering

Select a minimum of 15 credit hours from the following list of courses (approval of the department is required):

Environmental Engineering

ENGR 225, Thermodynamics, Fluid Mechanics, Heat & Mass Transfer (4)
GEOL 321, Hydrogeology (3)
ECIV 351, Engineering Hydraulics and Hydrology (3)
ECIV 361, Water Resources Engineering (3)
ECIV 362, Solid and Hazardous Waste Management (3)
ECIV 368, Environmental Engineering (3)
ECIV 370, Unit Operations and Processes in Environ. Engineering (3)
ECIV 450, Environmental Engineering Chemistry (3)
ECIV 460, Environmental Remediation (3)

Computer use is an integral part of the civil engineering curriculum. From required courses in computer programming and numerical analysis to subsequent use and development of civil engineering programs, the student fully utilizes the computer as a planning, analysis, design, and managerial tool.

All sequences are constructed to provide a balance of marketable skills and theoretical bases for further growth. With departmental approval other sequences can be developed to meet students' needs.

- Graduates will have a thorough knowledge of the technical requirements for the practice of the profession of civil engineering and be prepared for advanced scholarship.

Creativity:

- Graduates will be proficient in state of the art analytical and computational techniques for the modeling, analysis and design of civil engineering systems.

Societal Awareness:

- Graduates will have an understanding of the legal, social economic and environmental constraints within which the civil engineering profession must operate.
- Graduates will be aware of the special role the profession of civil engineering plays in the protection of public health, safety and welfare.

Leadership Skills:

- Graduates will be aware of the moral and ethical standards expected of leaders in the profession of civil engineering.
- Graduates will be able to function effectively and lead professional teams as well as work independently.

Professionalism:

- Graduates will be aware of the moral and ethical standards expected of the leaders in the profession of civil engineering.
- Graduates will be prepared for and aware of the necessity for a lifetime of learning and continued professional growth including professional registration.

Graduate Program in Civil Engineering

The graduate programs in structural engineering, geotechnical engineering, engineering mechanics and environmental engineering prepare students for careers in industry, professional practice, research and teaching. Experience has shown that job opportunities are excellent for students who receive advanced degrees in civil engineering at Case Western Reserve University. Recent advanced degree recipients have found positions in universities, consulting firms, petroleum companies, plant design firms, and aerospace firms, among others.

Each student's program of course work and research is tailored to his or her interests, in close consultation with the faculty advisor. For students working toward the Master of Science degree there are two possible plans, A and B. In plan A, a research thesis is required. In plan B, a project and additional course work are substituted for the thesis. For students working toward the Doctor of Philosophy degree a research thesis is required.

Graduate Program in Engineering Mechanics

The graduate program in engineering mechanics prepares the students for a career in research and analysis in solid and computational mechanics. Courses in mechanics of solids, applied plasticity, damage mechanics, viscoelasticity, viscoplasticity, stability, dynamics, finite elements and boundary integral methods, computational mechanics, constitutive methods, fracture mechanics, plates and shells give the student the necessary knowledge and skill to study the behavior of modern materials and structures as well as advance the state of the art. For more information contact the chair of the Department of Civil Engineering.

Facilities

Bingham Structures Laboratory

The major component of this laboratory is a 14-foot by 60-foot structural test slab, which is the top flange of a 12-foot deep reinforced concrete box girder. Load and tiedown points are provided by 3-inch diameter holes spaced at 2-foot centers. Loading is accomplished by hydraulic jacks. The laboratory also contains 200k, 50k, 25k universal testing machines, and two (2) 55k MTS hydraulic actuators with a controller and a separate hydraulic service manifold system.

Fracture Mechanics Laboratory

This laboratory is equipped with two (2) MTS servo-hydraulic materials test systems. Capabilities include: fracture toughness evaluation of various materials, crack growth kinetics under different loading histories, and microstructural damage analysis and micromechanics studies. The second MTS unit is capable of applying simultaneous axial and torsional loads. An environmental chamber is available. There is equipment available for fracture surface characterization and image analysis and a grinding-polishing unit.

Structures and Materials Models Laboratory

This laboratory is a facility for both instructional and research use. Small-scale models made of different materials (steel, concrete, wood, plastic) are tested to study the response of the prototype structural elements and/or assemblies. It is equipped with four 42-inch by 72-inch steel testing tables and aluminum reaction frames, and a series of portable strain indicators and companion switch and balance units.

Bingham Concrete Laboratory

A well-equipped concrete laboratory is available for undergraduate instruction. A 100 percent humidity room is available for curing concrete specimens. Other equipment includes a concrete mixer, screening equipment, an air entrainment meter, facilities for prestressing specimens, and a 400k axial compression machine.

Environmental Engineering Laboratory

This laboratory is one in a suite of new laboratories that support environmental engineering teaching and research. The facilities include a teaching laboratory, an advanced instrumentation laboratory, a remediation research laboratory and an electronic classroom/software laboratory. The Environmental Engineering laboratory is equipped for conventional Standard Methods analysis of water, wastewater, soil, solid waste and air samples (pH meters, furnaces, ovens, incubators, hoods, etc.) and for anaerobic and aerobic microbiology work. The lab also offers generous bench top space for student teams to explore laboratory procedures and provides direct access to research, instrumentation, and computational facilities.

Environmental Instrumentation Laboratory

This laboratory is equipped for state-of-the-art analysis of sophisticated environmental contaminants. The room supports a computer controlled Dionex DX-500 IC/HPLC system, a computer controlled Varian SPECTRAA 200/SIPS 10 (flame & furnace) AA system, and a computer controlled Hewlett Packard 6890 GC/MS analysis system for organic and inorganic pollutant analysis. Where appropriate, machines have been equipped with autosamplers to improve productivity.

Remediation Research and Colloid Science Laboratory

This laboratory is designed to support physical research on the applied science and design of remediation engineering and the analysis of colloidal particles. The laboratory provides a modeling floor for the assembly of laboratory scale remediation schemes, and provides immediate access to instrumentation and computational facilities for data analysis.

Soil Mechanics Laboratory

This laboratory has a full array of both instructional and research units; notable are automated triaxial units for generalized extension and compression tests, units permitting simultaneous application of hydrostatic, axial, and torsional static and dynamic stresses, a cubical device for true triaxial testing, units by means of which one dimensional consolidation in the triaxial cell can be automatically achieved, and various pore pressure force and deformation measuring devices. Tests are monitored and instantly evaluated by data acquisition-computer systems. Also available is a longitudinal and torsional resonant column device and a large size oedometer equipped with bender elements. The laboratory has a SP2000 high speed camera to study dynamic phenomena and a Bioquant surface analyzer to study fabric. A 20 g-tons fully automated centrifuge with a servo-hydraulic earthquake shaker is in operation. A controlled climate room is in regular use.

The Asphalt Concrete Laboratory

This laboratory is properly equipped to prepare and test (following ASTM standard specifications) both cylindrical and beam asphalt concrete specimens. Engineering and material properties of asphalt concrete specimens, such as Marshall stability, resilient modulus, Poisson's ratio, fracture toughness, and fatigue characteristics, among others, can be determined in a controlled temperature environment between 20° F and 100° F.

Image Processing Laboratory

The department has a New Image Processing Laboratory for development of automatic visual inspection methods for pavements, structures and other materials. Equipment available includes:

- Spectral Dynamics Corp. SD330A Real Time Spectrometer
- Ariel DSP-16 2-channel, 16-bit A/D system with 2 megabytes of memory/50kHZ conversion rate
- Ariel TMS320025 Processing Board for real time FFT
- Matrox MVP-AT Display System with 1024 x 1024 pixel display with 16.7 million simultaneous colors (with NP accelerator)
- PC/AT 486 and Pentium class computers with interconnection to Data Acquisition equipment
- HP Scanner
- Spin Physics SP2000 High-speed video camera and recorder. Maximum recording speed of 12000 frames/second.

Over 30 various video cameras with both CCD and tube sensors and a wide range of image speeds and luminosity requirements are available. Both color and black/white systems in standard RS-170, NTSC, RGB, and high- resolution formats are used in the lab.

Neff Civil Engineering Undergraduate Computer Laboratory

This laboratory provides Civil Engineering students with access to all the computer resources needed for both course work and research. The laboratory is supplemented by other facilities provided by the University. The Neff Laboratory has Pentium class computers running Windows/NT operating system. All of the computers in the Neff lab can act as independent workstations or provide access via a fiber optic link to other campus computers.

Computational Mechanics Laboratory

This laboratory includes seven (7) SUN workstations running UNIX, for graduate instructional and research use. The workstations are connected to the network via a fiber optic link.

Research

Research under way in civil engineering includes work in analytical, design and experimental areas and is sponsored by industry, state, and federal government sources. Major areas of research interest are:

Structures

Random vibration
Engineering materials
Behavior of reinforced and prestressed concrete
Wind engineering
Small-scale modeling under static and dynamic loads
Earthquake analysis and design of structures
Fatigue strength of reinforced concrete bridge decks
Finite element methods
Boundary element method
Passive and active control of the vibration of structures
Transient response of nonlinear structures
Blast loading of structures

Engineering Mechanics

Adaptive finite element and boundary element methods
Transient response of nonlinear layered composites
Modeling of micro electromechanical systems
Finite element and boundary element modeling of piezoelectric material
Biomechanics of the human mid face and mandible
Finite element modeling of coupled systems
Fracture mechanics of brittle matrix composites
Modeling of concrete, of geomaterials and of asphalt concrete
Constitutive theories and numerical implementation; plasticity, viscoplasticity, viscoelasticity and damage mechanics
Shape memory alloys, smart materials
Finite deformation viscoelasticity and numerical implementation; application to rubber materials
High and low-cycle fatigue
Fracture mechanics of steel, concrete, and ceramics
Plasticity of metal matrix composites
Structural mechanics of implants

Geotechnical/Pavement Materials

Static behavior of anisotropic clays and sands
Soil liquefaction
Fracture of over consolidated clay
Bifurcation and shear banding in soils
Centrifuge modeling of static and dynamic soil behavior
Dynamic soil structure interaction
Video imaging analysis of pavement surface distress
Non-destructive testing evaluation of soils and pavement materials
Micromechanical behavior of asphalt concrete under fatigue loading
Measurement of dynamic soil properties
Vibration of high-speed trains
Stability of tailings dams

Environmental Engineering

Environmentally conscious manufacturing
Remediation of "old" metal-contaminated soils
Ex-situ "heap" remediation
Brownfields/structural remediation

Environmental modeling/software development
Environmental decision analysis
Geoenvironmental engineering
Preferential pathway flow development
Environmental fluid mechanics
Sediment remediation
Contaminated sediment dynamics
Colloid-facilitated contaminant transport in porous media
In-situ remediation of non-aqueous phase liquids
Influence of remediation techniques on hydraulic conductivity in clay soils
Forces at clay-water-contaminant interfaces
Environmental microbiology
Bioremediation

Civil Engineering (ECIV)

Undergraduate Courses

ECIV 160. Surveying and Computer Graphics (3)
Principles and practice of surveying; error analysis, topographic mapping, introduction to photogrammetry and GIS; CAD. Laboratory.

ECIV 211. Civil Engineering Materials (3)
Steel, concrete, wood, masonry, and fiber-reinforced plastic. Experiments, advanced reading, and field trips. Strength, stiffness, ductility, and other properties of materials. Experiments on the flexural, compressive, and shear behavior of structural elements. Laboratory. Coreq: ECIV 310.

ECIV 300. Undergraduate Research (3)
Research conducted under the supervision of a sponsoring Civil Engineering faculty member. Research can be done on an independent topic or as part of an established on-going research activity. The student will prepare a written report on the results of the research. Course may fulfill one technical elective requirement. Prereq: Consent of the instructor and department.

ECIV 310. Strength of Materials (3)
Stresses and deformations of structural, machine and biological elements; transformation of stress and strain tensors. Mechanical properties of materials. Analysis of indeterminate structures. Inelasticity, failure theories, fatigue. Introduction to the mechanics of solid deformable bodies. Energy methods, virtual work and column stability. Prereq: ENGR 200.

ECIV 320. Structural Analysis I (3)
Static, linear, structural analysis of trusses and frames for member force and deflections. Stiffness and flexibility formulations. Behavior of statically determinate and indeterminate systems. Prereq: ECIV 310 and ENGR 200.

ECIV 321. Structural Analysis II (3)
Stiffness and flexibility formulations for plane frames, grids, and space frame with classical and matrix methods. Introduction to nonlinear analysis and stability. Structural behavior of arches, cable networks, and other structural systems. Prereq: ECIV 320.

ECIV 322. Structural Design I (3)
Design of structures, beams, columns, beam-columns, and connections. Structures of steel and reinforced concrete. Design laboratory. Prereq: ECIV 320.

ECIV 323. Structural Design II (3)
Continuation of ECIV 322. Torsion of concrete members, reinforcing steel details, compression reinforced flexural members, two-way slabs, slender columns, torsion of steel members, lateral and local buckling of steel members, plate girders, prestressed concrete design and wood design. Design laboratory. Prereq: ECIV 320 and ECIV 322.

ECIV 330. Soil Mechanics (4)
The physical, chemical, and mechanical properties of soils. Soil classification, capillarity, permeability, and flow nets. One dimensional consolidation, stress and settlement analysis. Shear strength, stability of cuts, embankments, retaining walls, and footings. Standard laboratory tests performed for the determination of the physical and mechanical properties of soils. Laboratory. Prereq: ECIV 310.

ECIV 340. Construction Management (3)
Selected topics in construction management including specifications writing, contract documents, estimating, materials and labor, bidding procedures and scheduling techniques. The course is augmented by guest lecturers from local industries.

ECIV 341. Construction Scheduling and Estimating (3)
The focus is on scheduling, and estimating and bidding for public and private projects. This includes highways as well as industrial and building construction. The use of computers with the latest software in estimating materials, labor, equipment, overhead and profit is emphasized. Prereq: ECIV 340 and consent of instructor.

ECIV 351. Engineering Hydraulics and Hydrology (3)
Application of fluid statics and dynamics to Civil Engineering Design. Hydraulic machinery, pipe network analysis, thrust, hammer, open channel flow, sewer system design, culverts, flow gauging, retention/detention basin design. Applied hydrology, hydrograph analysis and hydraulic routing will also be introduced. Coreq: ENGR 225.

ECIV 360. Civil Engineering Systems (3)
Decision-making methods in civil engineering. Engineering economics. Linear and nonlinear programming; planning, scheduling, and CPM methods. Probability and reliability analysis for decisions with risk and uncertainty. Computer laboratory.

ECIV 361. Water Resources Engineering (3)
Water doctrine, probabilistic analysis of hydrologic data, common and rare event analysis, flood forecasting and control, reservoir design, hydrologic routing, synthetic streamflow generation, hydroelectric power, water resource quality, water resources planning. Prereq: ECIV 351.

ECIV 362. Solid and Hazardous Waste Management (3)
Origin, characterization and magnitude of solid and hazardous waste. Solid and hazardous waste regulation. Methods of waste disposal. Techniques for waste reclamation and recycling. Waste management planning.

ECIV 368. Environmental Engineering (3)
Principle and practice of environmental engineering. Water and waste water engineering unit operations and processes including related topics from industrial waste disposal, air pollution and environmental health.

ECIV 370. Unit Operations and Processes in Environmental Engineering (3)
Physical, chemical, and biological operations and processes for the treatment of water supplies and municipal, industrial, and hazardous waste streams. Emphasis will be given to theoretical understanding and analysis of the involved processes and the design of treatment operations. Laboratory. Prereq: ECIV 368.

ECIV 396. Civil Engineering Special Topics I (1-3)
Special topics in civil engineering in which a regular course is not available. Conferences and report. Prereq: Consent of instructor.

ECIV 397. Civil Engineering Topics II (3)
Special topics in civil engineering in which a regular course is not available. Conferences and report. Prereq: Consent of instructor.

ECIV 398. Civil Engineering Senior Project (3)
A project emphasizing research and/or design must be completed by all civil engineers.

Graduate Courses

ECIV 400T. Graduate Teaching I (0)
This series of three courses will provide Ph.D. students with practical experience in teaching at the University level and will expose them to effective teaching methods. Each course assignment will be organized in coordination with the student's dissertation advisor and the department chairperson. Assignments will successively require more contact with students, with duties approaching the teaching requirements of a faculty member in the Ph.D. student's area of study. Prereq: Ph.D. student in Civil Engineering.

ECIV 405. Solid Mechanics I (3)
Kinematics of deformation. Balance principles. The concept of stress. Consistent linearization. The concept of invariance in mechanics of solids. Variational principles. The principle of virtual work. Hyperelasticity. Application to Boundary Value Problems. Prereq: ECIV 310 or equivalent or consent of instructor.

ECIV 406. Constitutive Modeling Theories (3)
Review of continuum mechanics. Application of theories of thermodynamics to the development of consistent constitutive models. Fundamentals in physics of deformation and fracture. Identification and rheological classification of real solids. Constitutive equations for thermoelastic, plastic, viscoplastic, linear and nonlinear viscoelastic solids. Internal variables. Strain and stress space formulations. Micromechanical considerations. Relation to experimental results. Effects of anisotropy and inhomogeneity. Temperature effects. Gradient and nonlocal theories. Uniqueness theorems. Extremum and variational principles. Stability. Prereq: ECIV 405 or consent of instructor.

ECIV 411. Applied Elasticity (3)
General analysis of deformation, strain, and stress. Elastic stress-strain relations and formulation of elasticity problems. Solution of elasticity problems by potentials. Simple beams. The torsion problem. Thick cylinders, disks, and spheres. Energy principle and introduction to variational methods. Elastic stability. Matrix and tensor notations gradually introduced, then used throughout the course. Prereq: ECIV 310 or equivalent.

ECIV 415. Structural Modeling and Experimental Methods (3)
Types of structural behavior, structural modeling, dimensional analysis and similitude requirements. Experimental stress analysis review. Fabrication, instrumentation and testing of small-scale models (steel, plastic, aluminum, wood). Materials and techniques. Case studies of models in design. Prereq: ECIV 211, ECIV 320 and consent of instructor.

ECIV 420. Finite Element Analysis (3)
Computational methods for treating material and geometric nonlinearities. Finite Element, Finite Difference and Boundary element methods. Transient analysis methods, alternative mesh descriptions: Lagrangian, Eulerian, and arbitrary Lagrangian Eulerian. Generalized finite element methods and particle methods. Applications to advanced problems in mechanics. Prereq: ECIV 310 or consent of instructor.

ECIV 421. Advanced Reinforced Concrete Design (3)
Properties of plain and reinforced concrete, ultimate strength of reinforced concrete structural elements, flexural and shear design of beams, bond and cracking, torsion, moment redistribution, limit analysis, yield line analysis of slabs, direct design and equivalent frame method, columns, fracture mechanics concepts. Prereq: ECIV 322 and consent of instructor.

ECIV 422. Advanced Structural Steel Design (3)
Selected topics in structural steel design including plastic design, torsion, lateral buckling, torsional-flexural buckling, frame stability, plate girders, and connections, including critical review of current design specifications relating to these topics. Prereq: ECIV 322.

ECIV 423. Prestressed Concrete Design (3)
Design of prestressed concrete structures, mechanical behavior of concrete suitable for prestressing and prestressing steels, load balancing, partial prestressing, prestressing losses, continuous beams, prestressed slab design, columns. Prereq: ECIV 323 or ECIV 421 and consent of instructor.

ECIV 424. Structural Dynamics (3)
Modeling of structures as single and multidegree of freedom dynamic systems. The eigenvalue problem, damping, and the behavior of dynamic systems. Deterministic models of dynamic loads such as wind and earthquakes. Analytical methods, including modal, response spectrum, time history, and frequency domain analyses. Prereq: ECIV 321 and consent of instructor.

ECIV 425. Structural Design for Dynamic Loads (3)
Structural design problems in which dynamic excitations are of importance. Earthquake, wind, blast, traffic, and machinery excitations. Human sensitivity to vibration, mechanical behavior of structural elements under dynamic excitation, earthquake response and earthquake-resistant design, wind loading, damping in structures, hysteretic energy dissipation, and ductility requirements. Prereq: ECIV 424.

ECIV 426. Structural Reliability (3)
Introduction to probability and random variables. Probability models for structural loads and strength. Estimation of the reliability of structures. Simulation methods. Reliability-based structural design. Prereq: Consent of instructor.

ECIV 427. Theory of Structural Stability (3)
Elastic buckling of columns, frames, thin plates, and shells using energy and differential equation methods. Beam columns, inelastic column behavior, and torsional and lateral buckling. Development and evaluation of design procedures for structural stability. Prereq: ECIV 321.

ECIV 430. Foundation Engineering (3)
Subsoil exploration. Various types of foundations for structures, their design and settlement performance, including spread and combined footings, mats, piers, and piles. Design of sand-drain installations and earth-retaining structures including retaining walls, sheet piles, and cofferdams. Case studies. Prereq: ECIV 330.

ECIV 431. Special Topics in Geotechnical Engineering (3)
Static and dynamic horizontal loading of piles; dynamics of pile driving; behavior of a group of piles including yielding. Soil-foundation-structure interaction due to static loading. Slope stability analysis using circular and non-circular failure surfaces. Use of available computer programs in analysis and design. Prereq: ECIV 430.

ECIV 432. Mechanical Behavior of Soils (3)
Soil statics and stresses in a half space-tridimensional consolidation and sand drain theory; stress-strain relations and representations with rheological models. Critical state and various failure theories and their experimental justification for cohesive and noncohesive soils. Laboratory measurement of rheological properties, pore water pressures, and strength under combined stresses. Laboratory. Prereq: ECIV 330 and consent of instructor.

ECIV 433. Soil Dynamics (3)
I-DOF and M-DOF dynamics; wave propagation theory; dynamic soil properties. Foundation vibrations, design of machine foundations. Seismology; elastic and elastoplastic response spectra, philosophy of earthquake-resistant design. One and two-dimensional soil amplification, liquefaction, dynamic settlement. Soil-structure interaction during earthquakes. Prereq: ECIV 330 and consent of instructor.

ECIV 435. Rock Mechanics and Design (3)
Physical properties and classification of intact rock and rock masses, rock exploration, engineering properties of rock, stresses in rock near underground openings. Rock tunneling, rock slope stability, bolting, blasting, grouting and rock foundation design. Prereq: ECIV 330.

ECIV 437. Pavement Analysis and Design (3)
Analysis and design of rigid and flexible airfield and highway pavements. Pavement evaluation and rehabilitations, overlay design. Prereq: ECIV 330.

ECIV 450. Environmental Engineering Chemistry (3)
Fundamentals of inorganic, organic, and physical chemistry with emphasis on the types of problems encountered in the environmental engineering field. Equilibria among liquid, gaseous, and solid phases; kinetics to the extent that time permits. A strong mathematical approach is taken in solving the equilibrium and kinetic problems presented. Equilibrium speciation software for solution of more complex problems. Topics that will be covered in the course include chemical equilibrium, acid/base reactions, mathematical problem solving approach, graphical approaches, titration curves, solubility of gases and solids, buffering systems, numerical solution of equilibrium problems, thermodynamics, oxidation-reduction reactions, principles of quantitative chemistry and analytical techniques, introduction to the use of analytical instrumentation, and chemical kinetics. Prereq: ECIV 368 or consent of instructor.

ECIV 460. Environmental Remediation (3)
Evolution of proactive environmental engineering to recover contaminated air, water, and soil environments. Lake and river remediation, contaminated sediments, indoor air quality, chemical spills, underground storage tanks, contaminated soils, solid and hazardous waste sites, superfund remediation. Prereq: ECIV 368 or consent of instructor.

ECIV 464. Environmental Engineering Microbiology (3)
This course presents an introduction to microbiology and microbial processes in natural and engineered environmental systems. Topics include redox chemistry and the stoichiometry of microbial reactions, biogeochemical cycling of nutrients and elements, microbial classification, cell metabolism, enzyme and growth kinetics, microbial ecology and diversity, biodegradation of environmental pollutants, and methods and applications in microbial ecology and environmental bioremediation.

ECIV 500T. Graduate Teaching II (0)
This series of three courses will provide Ph.D. students with practical experience in teaching at the University level and will expose them to effective teaching methods. Each course assignment will be organized in coordination with the student's dissertation advisor and the department chairperson. Assignments will successively require more contact with students, with duties approaching the teaching requirements of a faculty member in the Ph.D. student's area of study. Prereq: Ph.D. student in Civil Engineering.

ECIV 505. Solid Mechanics II - Advanced Elasticity (3)
Boundary value problems in linear and nonlinear elasticity using complex variables, Green's functions, and integral transform techniques; thermoelasticity; wave propagation; micromechanics and the equivalent inclusion method; dislocations; composite materials; thin films; energy methods. Prereq: ECIV 405 or consent of instructor.

ECIV 510. Computational Mechanics (3)
Computational methods for treating material and geometric nonlinearities. Return mapping algorithms for plasticity and viscoplasticity. Finite element, finite difference, and boundary element methods. Generalized finite element and particle methods. Applications to advanced problems in mechanics. Prereq: ECIV 406, ECIV 420, ECIV 505, or consent of instructor.

ECIV 520. Random Processes in Engineering (3)
Random vectors and second moment theory. Time and frequency domain characterization of random processes and fields. Poisson and Markov processes. Random vibration. The first passage problem. Digital simulation of random processes and analysis of time series. Applications focus on stochastic models for phenomena such as earthquakes, wind turbulence, ocean waves, traffic flow, and others related to civil engineering. Prereq: Consent of instructor.

ECIV 521. Stochastic Materials Behavior (3)
Applications of random processes to characterization of material structure; elements of quantitative stereology; micromechanical stochastic modeling of stress-strain behavior and static strength; modeling of fatigue strength and crack growth; stochastic simulation of material structure and deformation processes. Prereq: ECIV 520 and consent of instructor.

ECIV 560. Environmental Engineering Modeling (3)
Translation of the biology, chemistry and physics of environmental problems into mathematical models. Equilibrium and kinetic reaction systems, domain analysis. Lake, river and treatment process models. Convective, dispersive, reactive, sorptive, diffusive mass transport. Transport model calibration. Applications to bio-films, air pollution, spills, groundwater contamination.

ECIV 561. Groundwater Analysis (3)
Principles of mass transport through porous media, formulation of saturated and unsaturated flow equations in alternative coordinate systems, analytical and numerical solutions of flow equations, application of existing groundwater software, analysis of solute transport problems.

ECIV 583. Theory of Plates and Shells (3)
Analysis of flat plates subjected to various load and boundary conditions; coupled bending membrane response resulting from both material properties and large deformations; momentless theory of shells, classical bending analysis of shells of revolution, and higher order shell theory. Prereq: ECIV 411.

ECIV 584. Theory of Plasticity and Damage Mechanics (3)
The physics of plasticity and damage. Yield criteria, flow rules and hardening rules. Loading criteria. Proportional and non-proportional loading. Strain softening. Relation between elastic-plastic and rigid-plastic representations. Isotropic and kinematic linear and nonlinear hardening. Damage variables. Effective stress. Measurement of damage. Isotropic and nonisotropic damage. Plasticity coupled with damage. Boundary value problems. Dynamic problems. Applications to structural analysis, soil mechanics and metal forming. Prereq: ECIV 405 or ECIV 411 and consent of instructor.

ECIV 585. Fracture Mechanics (3)
Crack tip fields, stress intensity factors, singular solutions, energy changes with crack growth, cohesive zone models, fracture toughness, small scale yielding, experimental techniques, fracture criteria, J-integral, R-curve, fatigue cracks, fracture of composites, dynamic fracture. Prereq: ECIV 405 or ECIV 411 and consent of instructor.

ECIV 587. Advanced Mechanics Seminar (3)
Advanced topics in mechanics of solids. Thermodynamics with internal variables; thermoelasticity; plasticity; gradient theories; finite theories of plasticity; damage mechanics; endochronic plasticity; non-linear fracture mechanics; probabilistic mechanics. Prereq: ECIV 406, ECIV 420, ECIV 505 or consent of instructor.

ECIV 600T. Graduate Teaching III (0)
This series of three courses will provide Ph.D. students with practical experience in teaching at the University level and will expose them to effective teaching methods. Each course assignment will be organized in coordination with student's dissertation advisor and the department chairperson. Assignments will successively require more contact with students, with duties approaching the teaching requirements of a faculty member in the Ph.D. student's area of study. Prereq: Ph.D. student in Civil Engineering.

ECIV 601. Independent Study (1-18)
Plan B.

ECIV 611. Civil Engineering Graduate Seminar (0)
Distinguished outside speakers present current research in various topics of Civil Engineering. Graduate students also present technical papers based on thesis research.

ECIV 651. Thesis M.S. (1-18)
Plan A.

ECIV 660. Special Topics (1-18)
Topics of special interest to students and faculty. Topics can be those covered in a regular course when the student cannot wait for the course to be offered.

ECIV 701. Dissertation Ph.D. (1-18)

ECIV 702. Appointed Dissertation Fellow (9)

Department of Electrical Engineering and Computer Science

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The Department of Electrical Engineering and Computer Science spans the technologies at the forefront of our economy and our society. Professionals in these fields are responsible for developing microprocessors and personal computers, and the operating systems, computer software, and Internet applications which run on them. Almost every modern device contains an integral computer chip. New developments in such areas as medical electronics, automotive safety and control, automated manufacturing, and entertainment electronics continue to provide opportunities for our graduates.

The Department of Electrical Engineering and Computer Science (EECS) is structured into four programs: electrical engineering, computer engineering, systems and control engineering, and computer science. Each area offers a degree program which leads to the Bachelor of Science degree. All engineering programs in the department are accredited by the Accreditation Board for Engineering and Technology (ABET). The department also offers a Bachelor of Arts in computer science for those students who wish to combine a technical degree with a broad education in the liberal arts. At the graduate level the department offers the Master of Science and Doctor of Philosophy degrees in electrical engineering, computer engineering, systems & control engineering, and computing and information sciences.

History

The Electrical Engineering component of the department taught its first electrical engineering class in 1886 making it one of the oldest in the nation. The department has always been innovative and first in many things. The Systems & Control Engineering program was the first of its kind to be accredited by ABET and grew out of the Systems Research Center, originally founded in 1959. The computer engineering program was the nation's first ABET accredited computer engineering program.

Education

The EECS department is dedicated to producing high-quality graduates who will take positions of leadership. We recognize that the increasing role of technology in virtually every facet of our culture— communications, transportation, health care, the environment, and even our system of wealth distribution — makes it vital that engineering-oriented students have access to progressive and cutting-edge programs stressing excellence in:

- mastery of fundamentals
- creativity
- social awareness
- leadership skills and
- professionalism.

Emphasizing these core values will help ensure that tomorrow's graduates are valued and contributing members of our global society and that they will carry on the tradition of engineering leadership established by our alumni.

Statement of Educational Philosophy

Our goal is to graduate students who have fundamental technical knowledge of their profession and the requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance their fields.

To achieve this goal, the department offers a wide range of technical specialties consistent with the breadth of electrical engineering & computer science, including recent developments in the field. Because of the rapid pace of change in these fields our degree programs emphasize a broad technical background that equips students for future developments. As a result, our programs include a wide range of electives and our students are encouraged to develop individualized programs which can combine many aspects of electrical engineering and computer science. The department prepares students for careers in engineering with degrees in electrical engineering, computer engineering, computer science or systems & control engineering.

The department programs emphasize a mastery of fundamentals which will enable students to deal with new technological developments and interact with professionals in other fields. This is achieved by ensuring that our graduates have:

- a strong background in the fundamentals of chemistry, physics, mathematics, and computing
- an ability to design and construct engineering models by applying fundamental knowledge of mathematics, science, and engineering
- an ability to analyze engineering models utilizing state of the art engineering techniques, skills, and tools
- an ability to design and construct experiments to collect data, and to analyze and interpret the resulting data to develop and verify engineering models
- a broad education necessary to understand the impact of electrical engineering solutions in a modern society.

Technological development continues to result in new technologies and/or new problems. We ensure that our graduates are creative and able to apply their engineering knowledge to new problems by

- training them in the modeling, behavior, and specification of engineering components, systems, and/or processes
- training them in the planning, design, implementation, and operation of systems, components, and/or processes that meet engineering constraints
- providing significant design experience which involves problem definition, research, solution formulation, economics, communications, teamwork, and project management

We live in a complex technological society which requires that our graduates have a broad education necessary to understand the consequences of engineering solutions in the broader context of their impact upon people and the environment. We ensure that our graduates are socially aware by

- requiring that they have an extensive education in the humanities and social sciences
- by providing opportunities for and encouraging them to pursue additional studies in the humanities, social sciences and business.

We expect our students to become leaders in creating and applying new technologies by

- developing their written and oral communication skills, including the use of modern electronic tools such as presentation software, the World Wide Web, and e-mail
- providing group activities which develop teamwork and communications skills
- teaching them how to find technical information and research engineering problems, especially using electronic resources
- going outside the boundaries of individual textbooks as a preparation for life-long learning
- providing opportunities for students to develop and demonstrate leadership in professional organizations, engineering and research

We develop our students as professionals by developing their communications and leadership skills and additionally by

- training them to understand professional and ethical responsibility
- committing them to the highest standards of such responsibility and excellence in all their professional endeavors
- providing them with opportunities for professional development through the Co-Operative Education Program

Faculty

B. Ross Barmish, Ph.D. (Cornell University)
Department Chair, Nord Professor
Control systems, robustness, probabilistic methods, Monte Carlo simulation

Randall D. Beer, Ph.D. (Case Western Reserve University)
Professor
Computational neuroscience, autonomous robotics

Michael S. Branicky, Sc.D. (Massachusetts Institute of Technology)
Associate Professor
Intelligent systems and control, hybrid systems, learning, real-time and distributed control over networks, applications to robotics and flexible manufacturing

Marc Buchner, Ph.D. (Michigan State University)
Associate Professor
Computer simulation of complex systems, control of industrial systems, analysis of discrete event and combined systems

Vira Chankong, Ph.D. (Case Western Reserve University)
Associate Professor
Large-scale and multi-objective optimization and its application to engineering problems, manufacturing and production systems, improvement of magnetic resonance imaging, decision theory, and risk analysis

Funda Ergun, Ph.D. (Cornell University)
Schroeder Assistant Professor
Program testing routing and quality of service in high speed networks, packet classification, randomized algorithms, learning theory

George W. Ernst, Ph.D. (Carnegie Institute of Technology)
Associate Professor
Learning problem solving strategies, artificial intelligence, expert systems, program verification

Steven L. Garverick, Ph.D. (Massachusetts Institute of Technology)
Associate Professor
Mixed-signal integrated circuit design, microelectromechanical system integration, sensor/actuator interfacing, data conversion, wireless communication, analog neural network circuits, medical instrumentation

Dov Hazony, Ph.D. (University of California, Los Angeles)
Professor
Network syntheses, ultrasonics, communications

Vincenzo Liberatore, Ph.D. (Rutgers)
Assistant Professor
Distributed Systems, internet computing, randomized algorithms

Wei Lin, Ph.D. (Washington University)
Associate Professor
Nonlinear dynamic systems and geometric control theory, H-infinity and mixed H-2/H-infinity and robust control, adaptive control, system parameter estimation, adaptive and nonlinear control for robotics manipulators

Kenneth Loparo, Ph.D. (Case Western Reserve University)
Professor
Stability and control of nonlinear and stochastic systems, analysis and control of discrete event systems, intelligent control systems and failure detection. Recent applications work focuses on the control and failure detection of rotating machines.

Behnam Malakooti, Ph.D. (Purdue University)
Professor
Industrial engineering, computer-aided manufacturing, man-machine systems, AI, Multiple criteria decision making and optimization

Mehran Mehregany, Ph.D. (Massachusetts Institute of Technology)
Silicon and silicon carbide microelectromechanical systems (MEMS), micromachining and microfabrication and related integrated circuits, materials, and modeling issues

Frank Merat, Ph.D. (Case Western Reserve University), PE (Ohio)
Associate Professor and Associate Chair for Undergraduate Studies
Wireless networks, RF communications, optical MEMS devices, computer vision and image processing, neural networks

Mihajlo D. Mesarovic, Ph.D. (Serbian Academy of Science)
Cady Staley (Hanna) Professor
Complex systems theory, global issues and sustainable development

Wyatt Newman, Ph.D. (Massachusetts Institute of Technology)
Professor
Mechatronics, high -speed robot design, force and vision-based machine control, artificial reflexes for autonomous machines, rapid prototyping, agile manufacturing

Gultekin Ozsoyoglu, Ph.D. (University of Alberta, Canada)
Professor
Databases, multimedia computing, digital libraries

Z. Meral Ozsoyoglu, Ph.D. (University of Alberta, Canada)
Professor
Database theory, logic databases, database query and optimization

C.A. Papachristou, Ph.D. (Johns Hopkins University)
Professor
VLSI design and CAD, computer architecture and parallel processing, design automation, embedded system design

Stephen M. Phillips, Ph.D. (Stanford University), PE (Ohio)
Associate Professor
Applications of control and signal processing to robotics and automation

Andy Podgurski, Ph.D. (University of Massachusetts at Amherst)
Associate Professor
Software engineering methodology and tools, software architecture and design, distributed systems, software testing and reliability estimation

Daniel Saab, Ph.D. (University of Illinois at Urbana-Champaign)
Associate Professor
Computer architecture, VLSI system design and test, CAD design automation

S. Cenk Sahinalp, Ph.D. (University of Maryland)
Assistant Professor
Design, analysis and experimental evaluation of algorithms for pattern matching and indexing; data compression, communication networks and computational molecular biology

N. Sreenath, Ph.D. (University of Maryland)
Associate Professor
Large-scale systems, policy analysis, sustainable development, integrated assessment, global and environmental issues (water resources and global climate change), control theory applications and medical informatics

Massood Tabib-Azar, Ph.D. (Rensselaer Polytechnic Institute)
Professor
Semiconductor material and device characterizations, optical signal processing, novel high-frequency and high-power devices and circuits, spectroscopy and low temperature measurement, novel super-resolution near-field imaging probes, quantum computing

Lee J. White, Ph.D. (University of Michigan)
Professor and Associate Chair for Graduate Studies
Software testing, current projects include regression testing, study of domain testing, specification-based testing and testing of object-oriented software

Darrin Young, Ph.D. (University of California, Berkeley)
Assistant Professor
Micromachined sensors, high-Q passive components and integrated low power analog circuits for wireless communications

GQ (Guo-Qiang) Zhang, Ph.D. (Cambridge University, England)
Associate Professor
Programming languages, theory of computation, logic and topology in computer science

Associated Faculty

Secondary Faculty

Coleman B. Brosilow, Ph.D. (Brooklyn Polytechnic Institute)
Professor, Chemical Engineering

Robert V. Edwards, Ph.D. (Johns Hopkins University)
Professor, Chemical Engineering

Joseph Koonce, Ph.D. (University of Wisconsin, Madison)
Professor, Biology Department

Adjunct Faculty

Joan Carletta, Ph.D. (Case Western Reserve University)
Adjunct Assistant Professor

Howard Chizeck, Sc.D. (Massachusetts Institute of Technology)
Adjunct Professor

Benjamin F. Hobbs, Ph.D. (Cornell University)
Adjunct Professor

Pat Howard, Ph.D. (Case Western Reserve University)
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Adjunct Assistant Professor

Geoffrey Lockwood, Ph.D. (University of Toronto, Canada)
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Adjunct Assistant Professor

Peter Tsivitse
Adjunct Professor

Clayton Van Dorn, Ph.D. (Syracruse University)
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Chris Zorman, Ph.D. (Case Western Reserve University)
Adjunct Assistant Professor

Emeritus Faculty

Paul C. Claspy, Ph.D. (Case Institute of Technology)
Emeritus Associate Professor
Communications, and imaging, lasers and electro-optics
Robert E. Collin, Ph.D. (Imperial College, University of London, England)
Emeritus Professor
Electromagnetic theory, antennas, propagation, microwave components and systems
Sheldon Gruber, Sc.D. (Massachusetts Institute of Technology)
Emeritus Professor
Signal processing, machine vision and industrial inspection
Wen H. Ko, Ph.D. (Case Institute of Technology)
Emeritus Professor
Solid state sensors and devices, biomedical implants, telemetry
Irv Lefkowitz, Ph.D. (Case Institute of Technology)
Emeritus Professor
Automation and computer control of industrial processes
Osman K. Mawardi, Ph.D. (Harvard University)
Emeritus Professor
Plasma Physics, energy conversation and storage, applied superconductivity
Harry W. Mergler, Ph.D. (Case Institute of Technology)
Leonard Case Emeritus Professor
Digital systems, systems engineering, logical design computer control, metrology
Yoh-Han Pao, Ph.D. (Pennsylvania State University)
George S. Dively Emeritus Professor
Pattern recognition, signal and image processing, computational intelligence, intelligent systems
Frederick J. Way III
Emeritus Professor

Research Activities

EECS programs at Case Western Reserve encompass a wide spectrum of activities. Some of the major activities include biorobotics and computational intelligence, automation and robotics, solid-state devices and MEMS, communications, nanoelectronics and nanometrology techniques, global and large-system modeling, software engineering,and databases and bioinformatics. Much of this research is multi-disciplinary in nature involving faculty members from Materials Science and Engineering, Biology, Psychology, Civil Engineering, and Mechanical and Aerospace Engineering.

The faculty of the department actively pursue research in the areas described below. Students pursue their thesis research under the supervision of a faculty member who is a recognized authority in his field. Support for thesis research comes from a related research project or program under the direction of the faculty. For further information on research opportunities, the department chair should be contacted.

Algorithms - Professors Ergun, Liberatore and Sahinalp

Basic theoretical and applied work in randomized algorithms, program testing and correcting, learning theory, learning theory, multivariate optimization, data structures, string and sequence algorithms, combinatorial and statistical pattern matching and indexing, embedding of metric spaces, data compression and complexity of communication, algorithmic analysis of massive data sets, sketching and streaming models, parallel computation and circuit layouts, experimental algorithmics and performance evaluations.

Automation, Sensing, Actuation and Machine Intelligence - Professors Barmish, Branicky, Liberatore, Loparo, Malakooti, Merat, Newman, Pao and Phillips

Research activities include neural network applications; pattern recognition; artificial intelligence; hybrid systems, process automation; intelligent machine tool control; in-process gauging and control; adaptive learning methods applicable to robotics; system identification and adaptive control; intelligent control; the application of artificial intelligence to robotics systems and manufacturing; compliant control of robotics systems; non-contact inspection of production quality; machine vision for robotics applications; agile manufacturing systems; machine vision and image processing; rapid prototyping of computer-generated 3-D objects in engineering materials; computational intelligence, principles and applications; distributed computational intelligence in network client/server mode; computational intelligence and associative memories; robustness considerations and related statistical techniques.

Circuits and Computer-Aided Design - Professors Garverick, Young and Merat

Research activities include SiC circuits, and mixed-signal CMOS integrated circuit design for applications in MEMS, biomedical instrumentation, and robotics, MEMS RF high-Q tuning components for mobile communication circuits, MEMS sensors for biomedical and inertial sensing applications, microfabrication and integrated circuits process development.

Computer Networks - Professors Ergun, Liberatore, Malakooti and Sahinalp

Research activities include data dissemination, background distributed computing, distributed middleware and services, overlay networks, quality of service, routing, random graphs for network modeling, and packet filtering and classification; development of intelligent networks using intelligent mobile agents.

Computational Genomics - Professors Sahinalp, M. Ozsoyoglu, Pao and Buchner

Current research activities include: (1) computational studies of large scale genome duplication and other genome-wide rearrangements; (2) phylogenetics of the human genome, (3) algorithmic tools for pattern/motif search and discovery.

Computational Neuroscience and Autonomous Robotics - Professor Beer

Using computer simulation and theoretical analyses of models of complete neural/body/environment systems, this research pursues two objectives. First, it seeks to better understand the neural mechanisms of behavior in animals. Second, it seeks to apply biological control principles to the design of autonomous robots with the flexibility ad robustness of animals. The tools employed in this work include continuous-time recurrent neural networks, evolutionary algorithms, and dynamical systems theory. This research is highly interdisciplinary, and includes collaborators from the Department of Biology and the Department of Mechanical and Aerospace Engineering.

Control Applications - Professors Barmish, Branicky, Buchner, Loparo, Liberatore, Lin and Phillips

Topics include: (1) The development of anti-lock braking systems using fuzzy logic control methods; (2) Development of methods of automotive control and computer assisted tools for engineering analysis and design (e.g., development of computer based tools for system level failure mode effect analysis); (3) Developing technology for advanced power train, energy management, sensing and control strategies for electric vehicles; (4) the use of methods of control engineering to solve problems involving industrial and manufacturing processes; (5) developing advanced analysis and design tools for robotic assembly, agile manufacturing, (6) control over networks (QoS provisioning and multi-agent software).

Control, Filtering and Robustness - Professors Barmish, Lin and Loparo

Topics include: (1) nonlinear control theory work addressing questions regarding the behavior, stability and control of dynamic systems that are inherently nonlinear in the relationships between their inputs, outputs, and internal states; (2) stochastic control theory work involving the study of the behavior, stability and control of dynamic systems that possess an element of randomness in their operation over time; (3) stochastic filtering theory work, investigating the extraction of information about internal variables of a system on the basis of (possibly noise corrupted) measurements of system outputs; and (4) Robust control and analysis with emphasis on new Monte Carlo techniques and models for addressing system uncertainty.

Database Systems - Professors M. Ozsoyoglu and G. Ozsoyoglu

This research area focuses on performance issues in relational databases, database query processing and distributed database query processing, file allocation in distributed databases, database design, object-oriented databases, statistical database security problems, and relational interfaces for non-relational databases.

Design Methodologies and Design Automation - Professors Saab and Papachristou

This research area is concerned with the development of behavioral and structural level design methodologies and tools for the creation of VLSI-based systems and for multiple-processor architectures. Central to this work is the continued development of a third-generation design automation system for VLSI.

Electromagnetics, High Frequency Communications and Devices - Professors Hazony, Ko, Merat, Tabib-Azar and Young

Research activities include electromagnetic propagation and scattering, high frequency acoustic circuits, generation and detection of extremely sharp pulses, in situ monitoring in aggressive environments, biotelemetry, wireless communications for in situ arrays of biosensors.

Expert Systems - Professors Ernst, Malakooti, Merat, Paoand and Zhang

The research on expert systems is primarily concerned with using artificial intelligence techniques to represent and reason about knowledge. Current research includes (1) common-sense reasoning; (2) development of multiple criteria based expert systems for solving design and facility layout problems; and (3) applied research in a number of different challenging applications, such as fault diagnosis in discrete event systems. Most of these applications are based on knowledge which has been extracted from experts in the application domains.

Fault Detection and Diagnosis - Professors Loparo and Lin

Research combining advanced theoretical topics with solutions to industrial problems of high relevance and economic importance. Topics include: (1) the detection specific identification of failure events in systems and, when possible, the detection of incipient failures, through the use of nonlinear filtering of measured system inputs and outputs; and (2) the use of nonlinear dynamics and chaos theory for failure detection, the use of chaos concepts and other advanced model-based methods for vibration signature analysis.

Global Systems Analysis and Sustainable Development - Professor Mesarovic and Sreenath

This research addresses one of the most challenging tasks of systems science and systems engineering, i.e., to understand the world as a system and develop methods to assess the evolution of the system. In order to advance understanding of the global system, two principle obstacles are being addressed: complexity by using a multi-level, hierarchical architecture and uncertainty by interactive human/computer reasoning support process. The focus of the research is on interaction between global issues which represents a distinguishing characteristic of the global future (referred to as the global problematique). A range of issues are considered-from demographic transition and aging to carrying capacity, prospects for global climate change, impact of financial markets on development, etc. Collaborative research with a global network of universities is underway through the UNESCO Global-problematique Education Network Initiative (Genie). The Network is made up of fifteen universities from countries around the world strategically selected in order to provide a global coverage. Joint research with member institutions is conducted via the Internet. The research ranges from modeling and methods of complex systems analysis under true uncertainty analysis of specific issues such as global coordination of greenhouse gas emission reduction policies, water resources and health carrying capacity of Africa, etc.

Identification and Adaptive Control - Professors Lin and Buchner

Research directed towards specific application problems and the development of new theory. Topics include: (1) adaptive control of nonlinear systems, adaptive control of multi-input, multi-output systems having unknown and time varying input-output delays; (2) predictive adaptive control of non-minimum phase systems and the development computationally efficient methods of predictive control; (3) development and application of methods for real-time identification of parameters for linear systems having unknown input-output delays, and for nonlinear systems.

Industrial, Production, Operational, Management Systems - Professors Malakooti and Chankong

Optimization, multiple criteria decision making, and artificial intelligence techniques are used to improve quality, productivity, and cost efficiency of real-world problems including development of computer aided and integrated manufacturing/production planning and control; facility layout design, assembly line balancing; pattern recognition and clustering applied to group technology family formation; scheduling, machine set-up, tool life, and machinability. Research activities include applying optimization, decision making, multiple objectives (criteria), AI, artificial neural networks, pattern recognition/clustering to facility layout design, group technology, and assembly systems as well as developing multiple objective optimization and analysis for machine set-up, supervision, tool life, machinability, and sensing devices.

Intelligent Systems, Neural Nets And Fuzzy Logic - Professors Loparo, Pao, Branicky, Merat, Malakooti and Tabib-Azar

The use of methods of "machine intelligence" to accomplish control of systems. Particular topics of interest include: (1) the use of feed forward artificial neural nets to detect tool wear in parts machining processes, and to model load demand of electric power systems; (2) the use of fuzzy logic methods to attain anti-lock braking for automobiles, to control manufacturing processes and chemical processes, to detect events of gait in neuro-prosthetic systems that provide walking for paraplegics using electrical stimulation; (3) the analysis of combined discrete and continuous state 'hybrid' dynamic systems; and (4) novel computation techniques such as quantum computing and associated networks.

Logic, programming, and verification - Professor Zhang

Research activities include the semantics of programming languages and logic and models for reasoning about software, hardware, and security-critical systems.

Mathematical Modeling and Systems Analysis of Global Change Phenomena - Professors Mesarovic and Sreenath

The use of mathematical modeling of global economic and physical phenomena, in conjunction with computer simulation, to develop alternative scenarios of the future. This work involves a determination of what changes are possible within an environmental system, on the basis of the structure of mathematical models that represent its behavior (or hypotheses about its behavior).

Optimization and Decision Theory and Methods - Professors Malakooti and Chankong

Basic theoretical work and specific applications. Topics include: (1) Multi-objective optimization theory; (2) Algorithms for machine part formation problems; (3) Clustering algorithms for data compression; (4) Algorithms and tools for VLSI design; (5) Algorithms and methods for facility location and layout in manufacturing systems; (6) the use of systems analysis and decision theory methods to solve problems of the electric utility industry, such as quantification of the implications of transmission constraints for generation costs and resource planning.; (7) methods for the design of magnetic resonance imaging (MRI) pulse sequences, for clinical MR images. to allow for the removal of motion artifacts (e.g., in images of the liver) and enhancements of images specific tissue types; and (8) the application of systems analysis and decision theory methods to problems of information flow and control in health care.

Semiconductor Materials and Devices - Professors Tabib-Azar, Mehregany, Young, Garverick and Ko

Research activities include design, modeling, fabrication, testing, and application of a wide range of micro-to-nano systems, with particular emphasis on supporting materials technology, including silicon carbide. Example devices include micromachined components, sensors; actuators; opto-mechanical devices including scanners and switches; electronic devices; microwave probes; electromagnetic devices and filters, and wireless communication components and subsystems. Example applications are in fields such as transportation, telecommunications, space, biomedical, and industrial control.

Signal processing - Professors Buchner, Loparo, Merat and Pao

Research activities include neural network signal and information processing, image processing, time-frequency signal analysis, processing of genomic information, detection of tornados in radar images using wavelets, two-dimensional periodicity transforms.

Software Architecture and Design - Professors Podgurski , White and Zhang

The objective of this research is to develop, specify, and analyze prototypical or reference architectures for important families of software applications, such as those used in Internet commerce, manufacturing, biomedical control, and avionics, and to derive general principles and methodologies such as formal verification for the design of complex software systems.

Software Testing and Reliability - Professors White and Podgurski

This research focuses on improving the quality of software. One approach to testing software is to identify and correct defects applied to object-oriented software and specifically to GUI systems. Also there is a research project on data coverage testing, where the emphasis is to predict when testing can be stopped, as further testing can be shown to be only marginal in effectiveness.

Space Communications and Networks - Professors Ergun, Kinman, Ko, Malakooti, Merat, G. Ozsoyoglu, M. Ozsoyoglu, Papachrostou, Phillips, Sahinalp and Young

This research is primarily concerned with developing communications and networking solutions for near- and deep-space applications. Current research includes: (1) MEMS tunable antennas for power efficient wireless communications; (2) miniature silicon optical reflectors which can be electrostatically deformed and steered; (3) tiled arrays of processors which can be reconfigured for a variety of communications and signal processing applications; (4) semantic-based database inquiry and data warehousing for space assets; (5) protocols and control architectures for remote teleoperation of robots; (6) protocols and systems for the intelligent routing of data in space networks; (7) wireless networks of biosensors for monitoring of astronauts; and (8) efficient utilization of radio spectrum for space communications, performance modeling of radio communications using advanced coding schemes, Doppler and range measurements to space vehicles.

Facilities

Computer Facilities

The department computer facilities incorporate both UNIX (primarily Solaris) and Microsoft Windows-based operating systems on high end computing workstations for its educational and research labs. A number of file, printing, database and authentication servers support these workstations as well as the administrative functions of the department. Labs are primarily located in the Olin, Glennan and Smith buildings and are connected to each other via CWRUnet.

CWRUnet is a state-of-the-art, high-speed fiber optic campus-wide computer network that interconnects laboratories, faculty and student offices, classrooms and student residence halls at the University. CWRUnet is one of the largest fiber-to-desktop networks anywhere in the world. Every desktop has or will have a 1 Gbps (gigabit per second) connection to the rest of the campus network backbone, which runs on fault-tolerant 10 Gbps and faster fiber-optic links. In an effort to expand network availability to complement the wired network already in place, more than 1,000 wireless access points (WAPs) are being deployed, allowing students with laptops and wireless enabled PDAs to access CWRUnet resources from practically anywhere on campus.

Off campus users, through the use of CWRUnet's high capacity virtual private network (VPN) servers, can use their home dial-up or broadband connections to access many on campus resources as well as software as if they were physically connected to CWRUnet.

The department and the University also participate in the Internet2 project, which provides a high-speed, inter-University network infrastructure allowing for enhanced collaboration between institutions. The Internet2 infrastructure allows students, faculty and staff alike the ability to enjoy extremely high performance connections to other Internet2 member institutions.

Aside from standard services provided through a commodity Internet connection, CWRUnet users can take advantage of numerous on-line databases such as EUCLIDplus, the University Libraries' circulation and public access catalog, as well as Lexus-Nexus™ and various CD-ROM based dictionaries, thesauri, encyclopedias, and research databases. Many regional and national institutional library catalogs are accessible over the network, as well.

Department Laboratories

Smith Computer Lab

General purpose computer facilities for undergraduate instruction is provided by the Smith Laboratory which contains about 70 PCs, a number of Macintosh power PCs and ten SUN Sparc-5 UNIX workstations.

Jennings Computer Center Labs

Supported by an endowment from the Jennings Foundation, these labs provide our students with the education resources necessary both for their classes and to explore their interest in the art of computing.

Database and Multimedia Laboratory

Primarily funded by NSF equipment grants, this laboratory provides specialized equipment for research into multimedia and database systems.

VLSI Design Laboratory

Supported by the Silicon Research Corporation and industry, this laboratory has a number of UNIX workstations which run CAD software for VLSI design. This laboratory is currently used to develop testing techniques for digital design.

Autonomous Robotics Laboratory

Primarily funded by ONR and other federal sources, this laboratory has a number of computer workstations and robots which are used to conduct research into robotics, autonomous agents and biological simulation.

Electronic Circuits Lab

This laboratory has been primarily supported by the Hewlett-Packard Company and is the basic resource for students taking analog, digital and mixed-signal electronics classes. All instrumentation in the lab is computer-interfaced and students can even conduct experiments from their dorm rooms.

Analog Workstations

266 MHz NT workstations are equipped with LabView software. The workstations have HP-IB instrument interfaces connected to Hewlett-Packard 546xx oscilloscopes, 33120A Waveform Generators, 34401A Digital Multimeters, and E3631A power supplies.

Digital Workstations

450 MHz NT workstations and Sun Workstations support Xylinx FPGA hardware/software.

Additional instrumentation includes a Hewlett-Packard 4155B semiconductor parameter, Hewlett-Packard 54616TC mixed-signal test stations, Hewlett Packard logic analyzers, and Hewlett-Packard high-frequency oscilloscopes.

Lester J. Kern Computational Laboratory

This laboratory is used by students enrolled in "Electromechanical Energy Conversion," as well as for research in robotics and mechatronics. Laboratory facilities include: four lab stations for demonstrating machine characteristics and basic steady-state and dynamic system performance, four Sun SPARC UNIX workstations, and real-time data acquisition systems for interaction with lab experiments and control of machines.

Microcomputer Laboratory

This laboratory contains approximately 25 Microcomputers (these are mostly high end Pentiums and a few Macintosh Power PC's), along with a complement of laser printers, network connections (university fiber optic network and LAN), and scientific software (MATLAB, VISSIM, Mathematica, GINO, LINDO, etc.).

Process Control Laboratory

This laboratory contains process control pilot plants, computerized hardware for process control and demonstration/research facilities. This wet lab has access to steam and compressed air for use in the pilot plants.

Timken Foundation Dynamics and Control Laboratory

Contains mechanical, pneumatic and electrical laboratory experiments for teaching and research purposes. This includes PLCs, motors and robotics systems.

Global Systems Laboratory

This laboratory consists of various PC and Sun Sparc workstations containing databases from the UN, World Watch Institute, World Resources Institute, U.S. Government, etc., and policy and scenario analysis software.

Rockwell Automation Machinery Diagnostics and Control Laboratory

This laboratory is focused upon machinery diagnostics and failure prediction. Several test stands will provide instrumentation for machinery lifetime prediction and sensor development. Additional instrumentation will provide for remote operation of the test stands.

Micro-electronic Device Modeling and Characterization Lab

Affiliated with our MicroFabrication Laboratory MFL, this laboratory is equipped with dc measurement capabilities for evaluating semiconductor device performance. Device modeling is done on Sun SPARC and HP workstations.

Hans Jaffe Ultrasonics Laboratory

This laboratory is dedicated to the study and fabrication of specialized ultrasonic transducers. Facilities include pulsar receivers, specialized scopes, precision signal generators, and piezoelectric devices.

Center for Automation and Intelligent Systems Research

Supported in part by CAMP, Inc. through the State of Ohio's Thomas Edison research center program, this educational and research center contains multiple laboratories including:

- Mechatronics Laboratory
- Intelligent Systems Laboratory
- Multimedia and Computations Intelligent Systems Laboratory
- Control and Signal Processing Laboratories.

These laboratories are equipped with a diverse range of modern scientific and CAD workstations, computer controlled robots, materials handling devices, image processing and computer vision systems. These laboratories support research activities in robotics, agile manufacturing, multimedia internet applications to manufacturing, rotating machinery diagnostics, optical sensing and process control.

MicroFabrication Laboratory

This laboratory has been funded by many agencies including the State of Ohio and DARPA. The MicroFabrication Laboratory (MFL) is a state-of-the-art clean room facility for the fabrication of microelectromechanical systems (MEMS) and microelectronic devices. The Class 100 facility supports the University's strong interdisciplinary MEMS research program by providing on-campus fabrication capabilities for a broad range of research projects by investigators from a number of departments within the university; it is also accessible by external organizations for prototype fabrication and R&D. The MFL offers a broad spectrum of micromachining processes, including bulk and surface micromachining, wafer bonding, and micro-molding. These capabilities are augmented by a 2-micron CMOS process for the fabrication of integrated microsensors/microactuators.

The Center for Computational Genomics

Established by a $2.2 million grant from the Charles B. Wang Foundation, Inc. this interdisciplinary center (EECS, Genetics, and Biostatistics & Epidemiology) employs computer science to analyze the function of genes and proteins in health and disease. The Center's lab provides high-power computing resources (2GHz Dells with 1 GB DRAM) for computational genomics research.

PLC Control and Automation Laboratory

This laboratory uses Allen-Bradley PLC's for data acquisition and real-time control of complex processes. Currently the PLCs control a multi-train HO model system and a five-floor, two-car elevator system.

ENGR 131 Freshman Computing Lab

This lab is used to support the freshman ENGR 131 Elementary Computer Programming class. The laboratory provides personal computers and Lego Mindstorm robot kits which freshman use to learn about how computers can be used to control mechanisms, as well as to study C/C++ programming.

Undergraduate Programs

Electricial Engineering

The undergraduate program in electrical engineering, which leads to the Bachelor of Science in Engineering degree, provides a broad foundation in electrical engineering through combined classroom and laboratory work and prepares the student for entering the profession of electrical engineering as well as for further study at the graduate level.

Core courses provide the student with a strong background in mathematics, physical sciences and the fundamentals of engineering. Each electrical engineering student must take the following core courses:

Breadth Requirements:

- ENGR 131 Elementary Computer Programming
- ENGR 210 Introduction to Circuits and Instrumentation
- EECS 281 Logic Design and Computer Organization
- EECS 245 Electronic Circuits
- EECS 246 Signals and Systems
- EECS 309 Electromagnetic Fields I
- STAT 332 Statistics of Signal Processing
- EECS 321 Semiconductor Electronic Devices
- EECS 398L
- EECS 399L

Depth Requirement:

Each student must show a depth of competence in one technical area by taking at least three courses from one of the following seven areas. Note that this depth requirement may be met using a combination of the above core courses and a selection of open and technical electives.

Area I: Electromagnetics

EECS 309 Electromagnetic Fields I
EECS 310 Electromechanical Energy Conversion
EECS 311 Electromagnetic Fields II

Area II: Signals & Systems

EECS 246 Signals and Systems
EECS 313 Signal Processing
EECS 347 Network Synthesis
EECS 351 Communications and Signal Analysis
EECS 354 Digital Communications
EECS 396 Hybrid Systems

Area III: Computer Software

EECS 233 Data Structures
EECS 337 Systems Programming
EECS 338 Operating Systems

Area IV: Solid State

EECS 321 Semiconductor Electronic Devices
EMSE 314 Electrical, Optical and Magnetic Properties of Matter
EECS 322 Integrated Circuits and Electronic Devices

Area V: Control

EECS 304 Control Engineering I
EECS 310 Electromechanical Energy Conversion
EECS 383 Microprocessor Applications to Control
EECS 346 Engineering Optimization
EECS 396 Hybrid Systems

Area VI: Circuits

EECS 245 Electronic Circuits
EBME 310 Biomedical Instrumentation
EECS 344 Electronic Circuit Design
EECS 382 Microprocessor Based Design
EBME 418 Biomedical Electronics
EECS 426 MOS Integrated Circuit Design

Area VII: Computer Hardware

EECS 281 Computer Organization
EECS 382 Microprocessor Based Design
EECS 301 Computer Design Lab
EECS 314 Computer Architecture
EECS 315 Digital Systems Design

Statistics Requirement:

- STAT 332 Statistics of Signal Processing (STAT 333 may be substituted for STAT 332 with approval of advisor)
- Applied Statistics Elective (Class which uses statistics in some aspect of electrical engineering. Student may choose from EECS 351, EECS 354 or other class approved by advisor.)

Design Requirement:

- EECS 398L Senior Project I
- EECS 399L Senior Project II

In consultation with a faculty advisor, the student completes the program by selecting technical and open elective courses that provide in-depth training in one or more of a variety of specialties such as digital and microprocessor-based control, communications and electronics, solid state electronics and integrated circuit design and fabrication. With the approval of their advisors students may emphasize other specialties by selecting elective courses from other programs or departments.

Many courses have integral or associated laboratories in which students gain "hands-on" experience with electrical engineering principles and equipment. Students have ready access to the laboratory facilities and are encouraged to work in the various laboratories during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in many of the wide variety of research projects being conducted within the program.

Bachelor of Science in Engineering Degree Major in Electrical Engineering

Freshman Year — Class-Lab-Credit Hours

Fall

HM/SS elective	(3-0-3)
CHEM 111 Chemistry I	(4-0-4)
MATH 121 Calculus I	(4-0-4)
ENGR 131 Elementary Computer Programming	(3-0-3)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education	(0-3-0)
Total	**(17-3-17)**

Spring

Open elective [a]	(3-0-3)
ENGR 145 Chemistry of Materials	(4-0-4)
PHYS 121 Physics I: Mechanics [b]	(4-0-4)
MATH 122 Calculus II	(4-0-4)
PHED 102 Physical Education	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

PHYS 122 Physics II Electricity & Magnetism	(4-0-4)
MATH 223 Calculus III	(3-0-3)
ENGR 210 Circuits and Instrumentation	(3-2-4)
EECS 281 Computer Organization, Logic Design	(3-2-4)
Total	(13-4-15)

Spring

HM/SS Sequence I	(3-0-3)
ENGR 225 Thermo, Fluids, Transport	(4-0-4)
MATH 224 Differential Equations	(3-0-3)
EECS 245 Electronic Circuits	(3-2-4)
EECS 309 Electromagnetic Fields I	(3-0-3)
Total	**(16-2-17)**

Junior Year — Class-Lab-Credit Hours

Fall

HM/SS Sequence II	(3-0-3)
ENGR 200 Statics & Strength of Materials	(3-0-3)
EECS 246 Signals & Systems	(3-2-4)
STAT 332 Statistics of Signal Processing [c]	(3-0-3)
Approved Tech. Elective [d]	(3-0-3)
Total	**(15-2-16)**

Spring

HM/SS Sequence III	(3-0-3)
EECS 321 Semiconductor Elect. Devices	(3-2-4)
Applied Statistics Req. [e]	(3-0-3)
Approved technical elective [d]	(3-0-3)
Approved technical elective [d]	(3-0-3)
Total	**(15-2-16)**

Senior Year

Fall

EECS 398L Senior Project Lab I [f, g]	(0-8-4)
ENGL 398N Professional Communications	(3-0-3)
Open Elective	(3-0-3)
Approved technical elective [d]	(3-0-3)
Approved technical elective [d]	(3-0-3)
Total	**(12-8-16)**

Spring

HM/SS elective	(3-0-3)
HM/SS elective	(3-0-3)
EECS 399L Senior Project Lab II	(0-8-4)
Open elective	(3-0-3)
Approved technical elective [d]	(3-0-3)
Total	**(12-8-16)**

Graduation Requirement: 128 hours total

a. Although not required students may elect to take ENGR 101 Freshman Engineering Field Service Project as their open elective in the freshman year.

b. Selected students may be invited to take PHYS 123, 124 in place of PHYS 121 and PHYS 122.

c. Students may replace this class with STAT 333 Uncertainty in Engineering and Science if approved by their advisor.

d. Technical electives will be chosen to fulfill the depth requirement and otherwise increase the student's understanding of electrical engineering. Courses used to satisfy the depth requirement must come from the department's list of depth areas and related courses. Technical electives not used to satisfy the depth requirement are more generally defined as any course related to the principles and practice of electrical engineering. This includes all EEAP courses at the 200 level and above and can include courses from other programs. All non-EEAP technical electives must be approved by the student's advisor.

e. This course must utilize statistics in electrical engineering applications and is typically EEAP 352 Digital Communications or EEAP 355 RF Communications. Other courses possible with approval of advisor.

f. Co-op students may obtain design credit for one semester of Senior Project Lab if their co-op assignment included significant design responsibility; however, the student is still responsible for such course obligations as reports, presentations and ethics assignments. Design credit and fulfillment of remaining course responsibilities are arranged through the senior project instructor.

g. B.S./M.S. students may also utilize EEAP 398/399 to fulfill eight credits of M.S. thesis provided their thesis has adequate design content to meet the requirements of EEAP 398/399. B.S./M.S. students should see their thesis advisor for details.

Minor in Electrical Engineering

Students enrolled in degree programs in other engineering departments can have a minor specialization by completing the following courses:

- EECS 245 Electronic Circuits I (4)
- EECS 246 Signals and Systems (4)
- EECS 281 Logic Design and Computer Organization (4)
- EECS 309 Electromagnetic Fields I (3)
- Approved Technical Elective (3)

Minor in Electronics

The department also offers a minor in electronics for students in the College of Arts and Science. This program requires the completion of 29 credit hours, of which 10 credit hours may be used to satisfy portions of the students' skills and distribution requirements. The following courses are required for the electronics minor:

- MATH 125 Mathematics I (4)
- MATH 126 Mathematics II (4)
- PHYS 115 Introductory Physics I (4)
- PHYS 116 Introductory Physics II (4)
- ENGR 131 Elementary Computer Programming (3)
- ENGR 210 Circuits and Instrumentation (4)
- EECS 246 Signals and Systems (4)
- EECS 281 Logic Design and Computer Organization (4)

Bachelor of Science in Engineering Degree Major in Computer Engineering

Freshman Year — Class-Lab-Credit Hours

Fall

Open elective or HM/SS elective [a]	(3-0-3)
CHEM 111 Chemistry I	(4-0-4)
MATH 121 Calculus I	(4-0-4)
ENGR 131 Elementary Computer Programming	(3-0-3)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education	(0-3-0)
Total	**(17-3-17)**

Spring

HM/SS elective or open elective [a]	(3-0-3)
ENGR 145 Chemistry of Materials	(4-0-4)
PHYS 121 Physics I: Mechanics	(4-0-4)
MATH 122 Calculus II	(4-0-4)
PHED 102 Physical Education	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

HM/SS Sequence I	(3-0-3)
PHYS 122 Physics II: Electricity & Magnetism	(4-0-4)
MATH 223 Calculus III	(3-0-3)
ENGR 200 Statics & Strength of Materials	(3-0-3)
EECS 233 Introduction to Data Structures	(3-2-4)
Total	**(16-2-17)**

Spring

HM/SS Sequence II	(3-0-3)
MATH 224 Differential Equations	(3-0-3)
ENGR 210 Circuits and Instrumentation	(3-2-4)
Technical Elective [b]	(3-0-3)
EECS 281 Comp. Organization Logic Design	(3-2-4)
Total	**(15-4-17)**

Junior Year — Class-Lab-Credit Hours

Fall

HM/SS Sequence III	(3-0-3)
MATH 304 Discrete Mathematics	(3-0-3)
EECS 337 Systems Programming	(3-2-4)
ENGR 225 Thermodynamics, Fluids, Transport	(4-0-4)
Technical elective [b]	(3-0-3)
Total	**(16-2-17)**

Spring

ENGL 398N Prof. Communications	(3-0-3)
EECS 301 Digital Laboratory	(0-4-2)
EECS 314 Computer Architecture	(3-0-3)
EECS 315 Digital Systems Design	(3-2-4)
EECS 338 Intro to Operating Systems [d]	(3-2-4)
or	
Technical elective [d]	(3-0-3)
Total	**(12-8-16) or (12-6-15)**

Senior Year

Fall

HM/SS elective	(3-0-3)
EECS 318 VLSI/CAD [d]	(3-2-4)
or	
Technical elective [c]	(3-0-3)
Technical elective [b]	(3-0-3)
Statistics elective	(3-0-3)
Open elective	(3-0-3)
Total	**(15-2-16) or (15-0-15)**

Spring

HM/SS elective	(3-0-3)
EECS 399M Comp. Eng. Design Project	(0-6-3)
Technical elective [b]	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(12-6-15)**

Graduation Requirement: 129 hours total

a. One of these must be a humanities/social science course

b. Technical electives are more generally defined as any course related to the principles and practice of computer engineering. This includes all EECS courses at the 200 level and above and can include courses from other programs. All non-EECS technical electives must be approved by the student's advisor.

c. The student must take either EECS 318 VLSI/CAD (Fall Semester) or EECS 338 Intro. to Operating Systems (Spring Semester), AND a three credit hour technical elective.

d. Chosen from MATH 380 Introduction to Probability, STAT 312 Basic Statistics for Engineering and Science, STAT 313 Statistics for Experimenters, STAT 332 Statistics for Signal Processing, STAT 333 Uncertainty in Engineering and Science.

Cooperative Education Program

There are many excellent Cooperative Education (CO-OP) opportunities for computer engineering majors. A CO-OP student does two CO-OP assignments in industry or government. The length of each assignment is a semester plus a summer which is enough time for the student to complete a significant computing project. The CO-OP program takes five years to complete because the student is typically gone from campus for two semesters.

B.S./M.S. Program

The department encourages students with at least a 3.5 grade point average to apply for admission to the five-year bachelors/master's program in the junior year. This integrated program, which permits substitution of M.S. thesis work for the senior design project, provides a high level of fundamental training and in-depth advanced training in the student's selected specialty. It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years.

Computer Engineering

The Bachelor of Science program in Computer Engineering is designed to give a student a strong background in the fundamentals of mathematics, physics, and computer engineering and science. A graduate of this program should be able to use these fundamentals to analyze and evaluate computer systems, both hardware and software. A graduate should also be able to design and implement computer systems, both hardware and software, which are state of the art solutions to a variety of computing problems. This includes systems which have both a hardware and a software component, whose design requires a well defined interface between the two, and the evaluation of the associated

Bachelor of Science Degree Major in Computer Science

Freshman Year — Class-Lab-Credit Hours

Fall

Open elective or HM/SS elective	(3-0-3)
CHEM 111 Chemistry I	(4-0-4)
MATH 121 Calculus I	(4-0-4)
ENGR 131 Elementary Computer Programming	(3-0-3)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education	(0-3-0)
Total	**(17-3-17)**

Spring

HM/SS elective or open elective	(3-0-3)
ENGR 145 Chemistry of Materials	(4-0-4)
PHYS 121 Physics I: Mechanics	(4-0-4)
MATH 122 Calculus II	(4-0-4)
PHED 102 Physical Education	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

HM/SS Sequence I	(3-0-3)
PHYS 122 Physics II Electricity & Magnetism	(4-0-4)
MATH 223 Calculus III	(3-0-3)
Technical elective [b]	(3-0-3)
ECES 281 Comp. Organization Logic Design	(3-2-4)
Total	**(16-2-17)**

Spring

HM/SS Sequence II	(3-0-3)
MATH 224 Differential Equations	(3-0-3)
Technical Elective [c]	(3-0-3)
MATH 304 Discrete Mathematics	(3-0-3)
EECS 233 Intro Data Structures	(3-2-4)
Total	**(15-2-16)**

Junior Year — Class-Lab-Credit Hours

Fall

HM/SS Sequence III	(3-0-3)
EECS 340 Algorithms and Data Structures	(3-0-3)
EECS 337 Systems Programming	(3-2-4)
Statistics elective [c]	(3-0-3)
Technical elective [c]	(3-0-3)
Total	**(15-2-16)**

Spring

HM/SS elective	(3-0-3)
EECS 345 Programming Language Concepts	(3-0-3)
EECS 343 Theoretical Computer Science	(3-0-3)
EECS 314 Computer Architecture	(3-0-3)
EECS 338 Intro to Operating Systems	(3-2-4)
Total	**(15-2-16)**

Senior Year

Fall

ENGL 398N Professional Communication	(3-0-3)
EECS 398M Software Engineering	(3-0-3)
Technical elective [e]	(3-0-3)
Open elective	(3-0-3)
Open elective [d]	(3-0-3)
Total	**(15-0-15)**

Spring

HM/SS elective	(3-0-3)
EECS 341 Intro. to Database Systems	(3-0-3)
EECS 391 Intro. to Artificial Intelligence	(3-0-3)
Technical elective [e]	(3-0-3)
Open elective	(3-0-3)
Total	**(15-0-15)**

Graduation Requirement: 127 hours total

a. One of these must be a humanities/social science course.
b. ENGR 210 is recommended because it provides flexibility in choice of major and advanced EECS courses.
c. Chosen from MATH 380 Introduction to Probability, STAT 312 Basic Statistics for Engineering and Science, STAT 313 Statistics for Experimenters, STAT 332 Statistics for Signal Processing, STAT 333 Uncertainty in Engineering and Science.
d. Course other than mathematics or computer science.
e. Technical electives are more generally defined as any course related to the principles and practice of computer science. This includes all EESC and MATH courses at the 200 level and above and can include courses from other programs. All technical electives which are not EECS or MATH courses must be approved by the students advisor.

engineering trade-offs. In addition to these program specific objectives, all students in the EECS department are exposed to societal issues, professionalism, and have the opportunity to develop leadership skills.

Minor In Computer Engineering

The minor has a required two course sequence followed by a two course sequence in either hardware or software aspects of computer engineering.

The following two courses are required for any minor in computer engineering:

- EECS 281 Logic Design and Computer Organization (or equivalent)
- EECS 233 Introduction to Data Structures

The two-course hardware sequence is:

- EECS 314 Computer Architecture
- EECS 315 Digital Systems Design

The corresponding two-course software sequence is:

- EECS 337 Systems Programming
- EECS 338 Introduction to Operating Systems

In addition to these two standard sequences, the student may design his/her own with the approval of the minor advisor. A student cannot have a major and a minor, or two minors, in both Computer Engineering and Computer Science because of the significant overlap between these subjects.

Cooperative Education Program

There are many excellent Cooperative Education (CO-OP) opportunities for computer engineering majors. A CO-OP student does two CO-OP assignments in industry or government. The length of each assignment is a semester plus a summer which is enough time for the student to complete a significant computing project. The CO-OP program takes five years to complete because the student is typically gone from campus for two semesters.

B.S./M.S. Program

Students with a grade point average of 3.2 or higher are encouraged to apply to the B.S./M.S. Program which will allow them to get both degrees in five years. The B.S. can be in Computer Engineering or a related discipline, such as mathematics or electrical engineering. Integrating graduate study in computer engineering with the undergraduate program allows a student to satisfy all requirements for both degrees in five years.

Computer Science

The Bachelor of Science program in Computer Science is designed to give a student a strong background in the fundamentals of mathematics and computer science. A graduate of this

Bachelor of Arts Degree Computer Science

Freshman Year

Fall

Course	Class-Lab-Credit Hours
Open elective	(3-0-3)
MATH 125 Mathematics I	(4-0-4)
ENGR 131 Elementary Computer Programming	(3-0-3)
GER course	(3-0-3)
GER course	(3-0-3)
PHED 101 Physical Education	(0-3-0)
Total	**(16-3-16)**

Spring

Course	Class-Lab-Credit Hours
ENGL 150 Expository Writing	(3-0-3)
MATH 126 Mathematics II	(4-0-4)
GER course	(3-0-3)
GER course	(3-0-3)
Open elective	(3-0-3)
PHED 102 Physical Education	(0-3-0)
Total	**(16-3-16)**

Sophomore Year

Fall

Course	Class-Lab-Credit Hours
EECS 281 Comp. Organization Logic Design	(3-2-4)
GER course	(3-0-3)
Logic Design technical elective [a]	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(15-2-16)**

Spring

Course	Class-Lab-Credit Hours
GER course	(3-0-3)
MATH 304 Discrete Mathematics	(3-0-3)
EECS 233 Intro Data Structures	(3-2-4)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(15-2-16)**

Junior Year

Fall

Course	Class-Lab-Credit Hours
EECS 337 Systems Programming	(3-2-4)
GER course	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(12-2-13)**

Spring

Course	Class-Lab-Credit Hours
EECS 338 Intro to Operating Systems	(3-2-4)
EECS 341 Intro to Database Systems	(3-0-3)
EECS 314 Computer Architecture	(3-0-3)
Open elective	(3-0-3)
Total	**(12-2-13)**

Senior Year

Fall

Course	Class-Lab-Credit Hours
EECS 340 Algorithms and Data Structures	(3-0-3)
Technical elective [a]	(3-0-3)
GER course	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(15-0-15)**

Spring

Course	Class-Lab-Credit Hours
Technical elective [a]	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(15-0-15)**

Graduation Requirement: 120 hours total

a. One technical elective must be a computer science course. The other two technical electives may be computer science, MATH or STAT courses.

program should be able to use these fundamentals to analyze and evaluate software systems and the underlying abstractions upon which they are based. A graduate should also be able to design and implement software systems which are state of the art solutions to a variety of computing problems; this includes problems which are sufficiently complex to require the evaluation of design alternatives and engineering trade-off's. In addition to these program specific objectives, all students in the EECS department are exposed to societal issues, professionalism, and have the opportunity to develop leadership skills.

The Bachelor of Arts program in Computer Science is a combination of a liberal arts program and a computing major. It is a professional program in the sense that graduates can be employed as computer professionals, but it is much less technical than the Bachelor of Science program in Computer Science. It is particularly suitable for students with a wide variety of interests. For example, students can major in another discipline in addition to computer science and routinely complete all of the requirements for the double major in a 4 year period. This is possible because over a third of the courses in the program are open electives. Furthermore, if a student is majoring in computer science and a second technical field such as mathematics or physics many of the technical electives will be accepted for both majors. Another example of the utility of this program is that it routinely allows students to major in computer science and take all of the pre-med courses in a 4 year period.

Minor In Computer Science (B.S. or B.S.E.)

For students pursuing a B.S. or B.S.E. degree, the following three courses are required for a minor in computer science:

- EECS 233 Introduction to Data Structures
- EECS 338 Introduction to Operating Systems
- EECS 340 Algorithms and Data Structures

A student must take an additional four credit hours of computing courses with the exclusion of ENGR 131. MATH 304 (Discrete Mathematics) may be used in place of three of these credit hours because it is a prerequisite for EECS 340.

Minor In Computer Science (B.A.)

For students pursuing B.A. degrees, the following courses are required for a minor in computer science:

- ENGR 131 Elementary Computer Programming
- EECS 233 Introduction to Data Structures
- MATH 125 Mathematics I

Two additional computing courses are also required for this minor.

Cooperative Education Program

There are many excellent Cooperative Education (CO-OP) opportunities for computer science majors. A CO-OP student does two CO-OP assignments in industry or government. The length of each assignment is a semester plus a summer which is enough time for the student to complete a significant computing project. The CO-OP program takes five years to complete because the student is typically gone from campus for two semesters.

B.S./M.S. Program

Students with a grade point average of 3.2 or higher are encouraged to apply to the B.S./M.S. Program which will allow them to get both degrees in five years. The B. S. can be in Computer Science or a related discipline, such as mathematics or electrical engineering. Integrating graduate study in computer science with the undergraduate program allows a student to satisfy all requirements for both degrees in five years.

Systems and Control Engineering

The systems and control engineering B.S. program provides the student with the basic concepts, analytical tools, and engineering methods which are useful in analyzing and designing complex technological and non-technological systems. Problems relating to modeling, decision-making, control, and optimization are studied. Some examples of systems problems which are studied include: computer control of industrial plants, development of world models for studying environmental policies, and optimal planning and management in large-scale systems. In each case, the relationship and interaction among the various components of a given system must be modeled. This information is used to determine the best way of coordinating and regulating their individual contributions to achieve the overall goal of the system. What may be best for an individual component of the system may not be the best for the system as a whole.

There are three elective sequences available within our B.S. degree curriculum:

Control Systems

The Control Systems sequence is directed toward developing skills in dynamic system modeling, analysis, automation, remote control, real-time data acquisition and feedback control.

Systems Analysis

The Systems Analysis sequence focuses on modeling, optimization, decision making and planning methods.

Industrial and Manufacturing Systems

The Industrial and Manufacturing Systems sequence provides education in the application of systems analysis, decision making and automation methods to industrial production and manufacturing problems.

All three sequences use concepts of modeling, data analysis, computer simulation, and optimization. Computers play a central role in the systems and control curriculum, not only for engineering and mathematical computation, but also for computer simulation, automatic control, real-time data acquisition and signal processing.

Minor Program In Systems and Control Engineering

A total of five courses (15 credit hours) are required to obtain a minor in systems and control engineering.

At least nine credit hours must be selected from:

- EECS 212 Signals, Systems and Control (3)
- EECS 214 Signals, Systems and Control Lab (1)
- EECS 304 Control Engineering I with Laboratory (3)
- EECS 346 Engineering Optimization (3)
- EECS 352 Engineering Economics and Decision Analysis (3)

The remaining credit hours can be chosen from EECS courses with the written approval of the faculty member in charge of the minor program in the Systems and Control Program. A list of suggested EECS courses to complete the minor is:

- EECS 110 Problem Solving & Systems Engineering
- EECS 324 Simulation Methods in Engineering
- EECS 313 Signal Processing
- EECS 306 Control Engineering II
- EECS 350 Production and Operational Systems
- EECS 360 Manufacturing and Integrated Systems

Cooperative Education Program

There are many excellent Cooperative Education (CO-OP) opportunities for systems and control engineering majors. A CO-OP student does two CO-OP assignments in industry or government. The length of each assignment is a semester plus a summer which is enough time for the student to complete a significant engineering project. The CO-OP program takes five years to complete because the student is typically gone from campus for two semesters.

B.S./M.S. Program

The department encourages students with at least a 3.2 grade point average to apply for admission to the five-year bachelors/master's program in the junior year. This integrated program, which permits substitution of M.S. thesis work for the senior design project, provides a high level of fundamental training and in-depth advanced training in the student's selected specialty. It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years.

Control Engineering and Signal Processing

EECS 306 Control Engineering II
EECS 396 Hybrid Systems
EECS 401 Digital Signal Processing

Bachelor of Science in Engineering Degree
Major in Systems and Control Engineering

Freshman Year — Class-Lab-Credit Hours

Fall

HM/SS elective	(3-0-3)
CHEM 111 Chemistry I	(4-0-4)
MATH 121 Calculus I	(4-0-4)
ENGR 131 Elementary Computer Programming	(3-0-3)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education	(0-3-0)
Total	**(17-3-17)**

Spring

Open elective [a]	(3-0-3)
ENGR 145 Chemistry of Materials	(4-0-4)
PHYS 121 Physics I: Mechanics [b]	(4-0-4)
MATH 122 Calculus II	(4-0-4)
PHED 102 Physical Education	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

PHYS 122 Physics II: Electricity & Magnetism [b]	(4-0-4)
MATH 223 Calculus III	(3-0-3)
ENGR 210 Circuits and Instrumentation	(3-2-4)
EECS 281 Computer Organization	(3-2-4)
Total	**(13-4-15)**

Spring

HM/SS Sequence I	(3-0-3)
ENGR 225 Fluid and Thermodynamics	(4-0-4)
MATH 224 Differential Equations	(3-0-3)
STAT xxx Statistical Methods Course [c]	(3-0-3)
ENGR 200 Statics & Strength of Materials	(3-0-3)
Total	**(16-0-16)**

Junior Year — Class-Lab-Credit Hours

Fall

HM/SS Sequence II	(3-0-3)
EECS 246 Signals and Systems	(3-2-4)
EECS 342 Introduction to Global Systems	(3-0-3)
EECS 324 Simulation Methods	(3-0-3)
Approved technical elective [e]	(3-0-3)
Total	**(15-2-16)**

Spring

HM/SS Sequence III	(3-0-3)
EECS 304 Control Engineering I	(3-0-3)
EECS 305 Control Lab I	(0-2-1)
EECS 346 Engineering Optimization	(3-0-3)
Approved technical elective	(3-0-3)
Open elective	(3-0-3)
Total	**(15-2-16)**

Senior Year

Fall

HM/SS elective	(3-0-3)
EECS 398N Senior Project Lab [d]	(0-8-4)
ENGL 398N Professional Communications	(3-0-3)
EECS 352 Eng. Econ. & Dec. Analysis	(3-0-3)
Approved technical elective [e]	(3-0-3)
Total	**12-8-16**

Spring

HM/SS elective	(3-0-3)
EECS 399N Engineering Projects Lab II	(0-8-4)
Approved Technical Elective [e]	(3-0-3)
Approved Technical Elective [e]	(3-0-3)
Approved Technical Elective [e]	(3-0-3)
Total	**(12-8-16)**

Graduation Requirement: 127 hours total

a. Although not required, students may elect to take ENGR 101, Freshman Engineering Service Project, as their open elective during the freshman year.
b. Selected students may be invited to take PHYS 124 in place of PHYS 121 and 122.
c. Choose from STAT 312, STAT 332, STAT 333.
d. Co-op students may obtain credit for the first semester of Senior Project Lab if their co-op assignment includes significant design responsibility. This credit can be obtained by submitting a suitable written report and making an oral presentation on the co-op work in coordination with the senior project instructor.
e. Technical electives from an approved list.

EECS 404 Digital Control
EECS 409 Discrete Event Systems
EECS 417 Introduction to Stochastic Control

Control Systems Analysis and Engineering

EECS 414 Complex Systems Modeling and Analysis
EECS 416 Engineering Optimization
EECS 429 Risk and Decision Analysis
OPRE 432 Simulation
OPRE 426 Stochastic Processes in Operations Research

Manufacturing, Industrial, and Operational Systems

EECS 350 Production and Operational Systems
EECS 360 Manufacturing and Integrated Systems
OPMT 351 Logistical Systems
OPMT 353 Quality Control and Management
EECS 450 Production and Operational Systems
EECS 460 Manufacturing and Integrated Systems
OPRE 424 Scheduling

Graduate Programs

Computer Engineering and Science Graduate Studies

The programs in computer engineering and computing and information sciences are similar in that they each require a strong background in both computer hardware and software, as well as a substantial amount of "hands-on," experience. The programs differ in that engineering is based mainly in physical sciences, while computer science is more strongly based in mathematical sciences as applied to more abstract notions such as properties of programming languages, analysis of algorithms, complexity considerations, and proof of correctness. The department believes that the success of its graduates at all levels is largely due to the emphasis on project and problem-oriented course material coupled with the broad-based curricular requirements. Doctoral dissertations must be original contributions to the existing body of knowledge in computer engineering and science.

Electrical Engineering and Applied Physics Graduate Studies

The electrical engineering program offers graduate study leading to the Master of Science and Doctor of Philosophy degrees. The programs are comprehensive and basic, emphasizing four major areas in which the faculty are actively engaged in research: (1) automation, sensing, intelligence and actuation; (2) solid state electronics; (3) electromagnetic, high frequency communications and devices; and (4) circuits, signal processing, and computer-aided design. Academic requirements for graduate degrees in engineering are as specified for The Case School of Engineering in this bulletin, however, some exceptions are noted below. All current rules and regulations for this department are detailed in a graduate student handbook, available from the department office, which supersedes any rules contained here. A number of teaching and research assistantships are available, on a competitive basis, for the full support of qualified students. In addition, a limited number of tuition assistantships are also available for partial support of graduate students.

Systems Engineering Graduate Studies

Graduate programs in systems and control engineering include the following areas of concentration: control theory (adaptive control, stochastic filtering and control, nonlinear control), optimization and decision theory (multi-objective and large scale system theory), control of industrial and manufacturing systems (facilities layout, flexible manufacturing), biomedical control system design and analysis (control of neural prostheses, automatic control of therapeutic drug delivery), energy systems (power distribution and production planning, load forecasting), and global and environmental system analysis and control.(resource constraints: water, energy etc., carrying capacity and global climate change).

Research funds are used to provide assistantships that support the thesis research of graduate students. Current research funding is provided by Elsag-Bailey, Rockwell Automation, the Ford Motor Company, the Cleveland Advanced Manufacturing Program (CAMP), the Electric Power Research Institute (EPRI), the National Institutes of Health (NIH), National Institute of Nursing Research(NINR),the National Science Foundation (NSF), the U.S. Department of Veterans Affairs-Rehabilitation Research and Development Program (VA-RR&D), the Office of Naval Research (ONR), the U.S. Agency for International Development (US-AID) and United National Education, Scientific Cultural Organization (UNESCO).

Electrical Engineering and Computer Science (EECS)

Undergraduate Courses

EECS 212. Signals, Systems, and Control (3)
Characterization of continuous-time signals and systems. Laplace transforms, constant coefficient differential equations. Modeling of dynamical systems. Introduction to control system analysis and design. Prereq: MATH 224.

EECS 214. Signals, Systems, and Control Laboratory (1)
A laboratory course based on the material in EECS 212. Analysis and simulation using MATLAB/Simulink. Laboratory experiments involving signal processing and control. Coreq: EECS 212.

EECS 216. Fundamental System Concepts (3)
Develops framework for addressing problems in science and engineering that require an integrated, interdisciplinary approach, including the effective management of complexity and uncertainty. Introduces fundamental system concepts in an integrated framework. Properties and behavior of phenomena regardless of the physical implementation through a focus on the structure and logic of information flow. Systematic problem solving methodology using systems concepts. Prereq: MATH 224.

EECS 233. Introduction to Data Structures (4)
The programming language C++; pointers, files, variant records, and recursion. Representation and manipulation of data: one-way and circular linked lists, doubly linked lists; the available space list. Different representations of stacks and queues. Representation of binary trees, trees and graphs. Hashing; searching and sorting. Laboratory. Prereq: ENGR 131.

EECS 245. Electronic Circuits (4)
Analysis of time-dependent electrical circuits. Dynamic waveforms and elements: inductors, capacitors, and transformers. First- and second-order circuits, passive and active. Analysis of sinusoidal steady state response using phasors. Laplace transforms and pole-zero diagrams. S-domain circuit analysis. Two-port networks, impulse response, and transfer functions. Introduction to nonlinear semiconductor devices: diodes, BJTs, and FETs. Gain-bandwidth product, slew-rate and other limitations of real devices. SPICE simulation and laboratory exercises reinforce course materials. Prereq: ENGR 210. Coreq: MATH 224.

EECS 246. Signals and Systems (4)
The sinusoidal steady state and phasor analysis. Bode plots and their relationship to the frequency domain representation of signals. Gain-bandwidth product, slew-rate and other limitations of real devices. Filter design. Frequency domain considerations including Fourier series and Fourier transforms. Sampling theorem. The Discrete Fourier Transform. The

z-transform and digital signal processing. Accompanying laboratory exercises which reinforce classroom lectures. Prereq: ENGR 210 and MATH 224.

EECS 251. Numerical Methods (3)
Introduction to basic concepts and algorithms used in the numerical solution of common problems including solving non-linear equations, solving systems of linear equations, interpolation, fitting curves to data, integration and solving ordinary differential equations. Computational error and the efficiency of various numerical methods are discussed in some detail. Most homework requires the implementation of numerical methods on a computer. Prereq: ENGR 131 and MATH 122.

EECS 281. Logic Design and Computer Organization (4)
Fundamentals of digital systems in terms of both computer organization and logic level design. Organization of digital computers; information representation; boolean algebra; analysis and synthesis of combinational and sequential circuits; datapaths and register transfers; instruction sets and assembly language; input/output and communication; memory. Prereq: ENGR 131.

EECS 285. Engineering in Community Service I (3)
Project-oriented course; students work on "real" engineering projects of benefit to the community and in partnership with community "customers." Project teams consists of a mix of sophomores, juniors, and seniors. Students perform engineering design tasks as appropriate to their technical background. Emphasis on teamwork, communication skills, customer awareness, and professional responsibility. Prereq: Sophomore standing in EECS.

EECS 290. Special Topics (1-18)
Limited to sophomores and juniors. Prereq: Consent of instructor.

EECS 301. Digital Logic Laboratory (2)
This course is an introductory experimental laboratory for digital networks. The course introduces students to the process of design, analysis, synthesis and implementation of digital networks. The course covers the design of combinational circuits, sequential networks, registers, counters, synchronous/asynchronous Finite State Machine, register based design, and arithmetic computational block. Prereq: EECS 281.

EECS 304. Control Engineering I with Laboratory (3)
Analysis and design techniques for control applications. Linearization of nonlinear systems. Design specifications. Classical design methods: root locus, bode, nyquist. PID, lead, lag, lead-lag controller design. State space modeling, solution, controllability, observability and stability. Modeling and control demonstrations and experiments single-input/single-output and multivariable systems. Control system analysis/design/implementation software. Prereq: EECS 212.

EECS 305. Control Engineering I Laboratory (1)
A laboratory course based on the material in EECS 304. Modeling, simulation, and analysis using MATLAB. Physical experiments involving control of mechanical systems, process control systems, and design of PID controllers. Prereq: EECS 212 or equivalent. Coreq: EECS 304.

EECS 306. Control Engineering II with Laboratory (3)
Advanced techniques for control of dynamic systems. State-space modeling, analysis, and controller synthesis; introduction to nonlinear control systems: phase plane methods, bang-bang control, time-optimal control; describing functions analysis and design techniques; discrete time systems and controllers. Advanced control design methods implementation. Prereq: EECS 304.

EECS 309. Electromagnetic Fields I (3)
Maxwell's integral and differential equations, boundary conditions, constitutive relations, energy conservation and Pointing vector, wave equation, plane waves, propagating waves and transmission lines, characteristic impedance, reflection coefficient and standing wave ratio, in-depth analysis of coaxial and strip lines, electro- and magneto-quasistatics, simple boundary value problems, correspondence between fields and circuit concepts, energy and forces. Prereq: MATH 223 and PHYS 122. Coreq: MATH 224.

EECS 310. Electromechanical Energy Conversion (4)
Electromechanical dynamics, modeling and control. Forces in quasistatic magnetic systems. Energy conversion properties of rotating machines. Analysis and control of DC servomotors, AC servomotors, reluctance machines, inductance machines, and magnetic bearing. Analysis of electromagnetic sensors. Electronic communication, torque linearization through computer controls and flux-vector control. Electromechanical properties are measured in the lab and high-performance controls are constructed and tested. Prereq: EECS 309.

EECS 311. Electromagnetic Fields II (3)
Boundary value problems, guided electromagnetic waves, rectangular and circular waveguides, strip lines, losses in waveguiding structures, scattering, wave optics and wave propagation in anisotropic media, ferrites and plasmas, resonant systems, cavities, microwave networks, multiport networks, scattering matrix formulation, radiation and antennas, radiation from dipoles, apertures and simple arrays. Prereq: EECS 309.

EECS 313. Signal Processing (3)
Fourier series and transforms. Analog and digital filters. Fast-Fourier transforms, sampling, and modulation for discrete time signals and systems. Consideration of stochastic signals and linear processing of stochastic signals using correlation functions and spectral analysis. Prereq: EECS 246.

EECS 314. Computer Architecture (3)
This course provides students the opportunity to study and evaluate a modern computer architecture design. The course covers topics in fundamentals of computer design, performance, cost, instruction set design, processor implementation, control unit, pipelining, communication and network, memory hierarchy, computer arithmetic, input-output, and an introduction to RISC and super-scalar processors. Prereq: EECS 281.

EECS 315. Digital Systems Design (4)
This course gives students the ability to design modern digital circuits. The course covers topics in logic level analysis and synthesis, digital electronics: transistors, CMOS logic gates, CMOS lay-out, design metrics space, power, delay. Programmable logic (partitioning, routing), state machine analysis and synthesis, register transfer level block design, datapath, controllers, ASM charts, microsequencers, emulation and rapid protyping, and switch/logic-level simulation. Prereq: EECS 281.

EECS 317. Computer Design Laboratory (2)
Sequence of laboratory projects provide practical experience in computer-aided design techniques for computer and digital system design. Hardware system modeled and simulated at register transfer and switching transistor level.

EECS 318. Computer-Aided Design (4)
With Very Large Scale Integration (VLSI) technology there is an increased need for Computer-Aided Design (CAD) techniques and tools to help in the design of large digital systems that deliver both performance and functionality. Such high performance tools are of great importance in the VLSI design process, both to perform functional, logical and behavioral modeling and verification to aid the testing process. This course discusses the fundamentals in behavioral languages, both VHDL and Verilog, with hands-on experience with state-of-the-art computer-aided design tools. Prereq: EECS 281 and EECS 321.

EECS 321. Semiconductor Electronic Devices (4)
Energy bands and charge carriers in semiconductors and their experimental verifications. Excess carriers in semiconductors. Principles of operation of semiconductor devices that rely on the electrical properties of semiconductor surfaces and junctions. Development of equivalent circuit models and performance limitations of these devices. Devices covered include: junctions, bipolar transistors, Schottky junctions, MOS capacitors, junction gate and MOS field effect transistors, optical devices such as photodetectors, light-emitting diodes, solar cells and lasers. Laboratory experiments to characterize some of the above devices. Prereq: EECS 309.

EECS 322. Integrated Circuits and Electronic Devices (3)
Technology of monolithic integrated circuits and devices, including crystal growth and doping, photolithography, vacuum technology, metalization, wet etching, thin film basics, oxidation, diffusion, ion implantation, epitaxy, chemical vapor deposition, plasma processing, and micromachining. Basics of semiconductor devices including junction diodes, bipolar junction transistors, and field effect transistors. Prereq: EECS 321.

EECS 324. Simulation Techniques in Engineering (3)
Discrete event systems and simulation concepts. Discrete event simulation with batch and interactive languages. Coreq: ENGL 398.

EECS 329. Design of Object-Oriented Systems (3)
This course provides an opportunity to gain an understanding of the concepts and technology of object-oriented systems and learn system design techniques that take full advantage of this technology. Students also develop competence in programming with the object-oriented features of C++. Prereq: EECS 233.

EECS 337. Systems Programming (4)
Lexical analyzers; symbol tables and their searching; assemblers, one-pass and two-pass, conditional assembly, and macros; linkers and loaders; interpreters, pcodes, threaded codes; introduction to compilation, grammar, parsing, and code generation; preprocessors; text editors, line-oriented and screen-oriented; bootstrap loaders, ROM monitors, interrupts, and device drivers. Laboratory. Prereq: EECS 233 and EECS 281.

EECS 338. Introduction to Operating Systems (4)
CPU scheduling, memory management, concurrent processes, semaphores, monitors, deadlocks, secondary storage management, file systems, protection, UNIX operating system, fork, exec, wait, UNIX System V IPCs, sockets, remote procedure calls, threads. Must be proficient in "C" programming language. Prereq: EECS 337.

EECS 340. Algorithms and Data Structures (3)
Efficient sorting algorithms, external sorting methods, internal and external searching, efficient string processing algorithms, geometric and graph algorithms. Prereq: EECS 233 and MATH 304.

EECS 341. Introduction to Database Systems (3)
Relational model, ER model, relational algebra and calculus, SQL, OBE, security, views, files and physical database structures, query processing and query optimization, normalization theory, concurrency control, object relational systems, multimedia databases, Oracle SQL server, Microsoft SQL server. Prereq: EECS 233.

EECS 342. Introduction to Global Issues (3)
This systems course is based on the paradigm of the world as a complex system. Global issues such as population, world trade and financial markets, resources (energy, water, land), global climate change, and others are considered with particular emphasis put on their mutual interdependence. A reasoning support computer system which contains extensive data and a family of models is used for future assessment. Students are engaged in individual, custom-tailored, projects of creating conditions for a desirable or sustainable future based on data and scientific knowledge available. Students at Case Western Reserve will interact with students from fifteen universities that have been strategically selected in order to give global coverage to UNESCO'S Global-problematique Education Network Initiative (GENIe) in joint, participatory scenario analysis via the internet.

EECS 343. Theoretical Computer Science (3)
Introduction to mathematical logic, different classes of automata and their correspondence to different classes of formal languages, recursive functions and computability, assertions and program verification, denotational semantics. Prereq: MATH 304. Cross-listed as MATH 343.

EECS 344. Electronic Analysis and Design (3)
The design and analysis of real-world circuits. Topics include: junction diodes, non-ideal op-amp models, characteristics and models for large and small signal operation of bipolar junction transistors (BJTs) and field effect transistors (FETs), selection of operating point and biasing for BJT and FET amplifiers. Hybrid-pi model and other advanced circuit models, cascaded amplifiers, negative feedback, differential amplifiers, oscillators, tuned circuits, and phase-locked loops. Computers will be extensively used to model circuits. Selected experiments and/or laboratory projects. Prereq: EECS 245.

EECS 345. Programming Language Concepts (3)
This course studies important concepts underlying the design, definition, implementation and use of modern programming languages including syntax, semantics, names/scopes, types, expression, assignment, subprograms, data abstraction, and inheritance. Imperative, object-oriented, concurrent, functional, and logic programming paradigms are discussed. Illustrative examples are drawn from a variety of popular languages, such as C++, Java, Ada, Lisp, and Prolog. Prereq: EECS 233, EECS 337.

EECS 346. Engineering Optimization (3)
Optimization techniques including linear programming and extensions; transportation and assignment problems; network flow optimization; quadratic, integer, and separable programming; geometric programming; and dynamic programming. Nonlinear optimization topics: optimality criteria, gradient and other practical unconstrained and constrained methods. Computer applications using engineering and business case studies. Prereq: MATH 201.

EECS 347. Network Synthesis (3)
Design techniques for the construction of filters, delayors, predictors, analog computer networks, and necessary and sufficient requirements for the realization of practical networks. Prereq: EECS 246 or equivalent.
EECS 348. Communication Electronic Cir (4)

EECS 350. Industrial and Production Systems Engineering (3)
Time and motion study, human factors and safety engineering, man-machine systems, quality control and reliability, project management, scheduling, sequencing, inspection and maintenance of industrial processes.

EECS 351. Communications and Signal Analysis (3)
Fourier transform analysis and sampling of signals. AM, FM and SSB modulation and other modulation methods such as pulse code, delta, pulse position, PSK and FSK. Detection, multiplexing, performance evaluation in terms of signal-to-noise ratio and bandwidth requirements. Prereq: EECS 246 or equivalent.

EECS 352. Engineering Economics and Decision Analysis (3)
Economic analysis of engineering projects, focusing on financial decisions concerning capital investments. Present worth, annual worth, internal rate of return, benefit/cost ratio. Replacement and abandonment policies, effects of taxes, and inflation. Decision making under risk and uncertainty. Decision trees. Value of information.

EECS 354. Digital Communications (3)
Fundamental bounds on transmission of information. Signal representation in vector space. Optimum reception. Probability and random processes with application to noise problems, speech encoding using linear prediction. Shaping of base-band signal spectra, correlative coding and equalization. Comparative analysis of digital modulation schemes. Concepts of information theory and coding. Applications to data communication. Prereq: EECS 351 recommended.

EECS 355. RF Communications (3)
Coverage of modern communications circuits and systems with a particular emphasis upon mobile communications. Cellular communications, modulation methods, user access schemes. Individual system components: tuned small signal amplifiers and power amplifiers, mixers, detectors, and frequency synthesizers. Low-power design considerations. Prereq: EECS 351.

EECS 356. Microwave Engineering (3)
Transmission lines and circuit analysis, waveguides, modes of propagation, impedance matching techniques, scattering matrix, waveguide components, striplines, resonators, microwave theory, filters, microwave solid state devices. Prereq: EECS 311.

EECS 358. Domain Theoretic Methods for Artificial Intelligence (3)
Resolution for propositional logic and completeness via Zorn's Lemma, Domain theory and topology through three-value logic. Default reasoning and extensions. Clausal logic for Scott domains and Smyth power domains. Power defaults theory and the semantics of nonmonotonic reasoning and disjunctive logic programming. Prereq: EECS 343, EECS 391, MATH 307, or PHIL 306. Cross-listed as MATH 350.

EECS 360. Manufacturing, Operations, and Automated Systems (3)
Introduction to design, modeling, analysis, and optimization of production, automation computer-integrated, and manufacturing systems. Topics include, design of products and processes, statistical quality control: confirming design, design of location/spatial problems, transportation and assignment problems, product-oriented layout (including assembly line balancing), process oriented layout (including quadratic assignment problem and steepest descent exchange heuristics), group technology and clustering, cellular and network flow layouts, machining supervisions optimization and numerical control. Tools for analysis for each of the above problems include: optimization, multiple criteria decision-making (MCDM), and heuristics for combinatorial problems. Applications to com-

puter science and engineering problems are also covered. Prereq: Junior or senior level standing in engineering or consent of instructor.

EECS 375. Autonomous Robotics (3)
Introduction to the design, construction and control of autonomous mobile robots. The first half of the course consists of focused exercises on mechanical construction with LEGO, characteristics of sensors, motors and batteries, and control strategies for autonomous robots. In the second half of the course, students design, build and program their own complete robots that participate in a public competition. All work is performed in groups. Biologically-inspired approaches to the design and control of autonomous robots are emphasized throughout. Prereq: Consent of instructor. Cross-listed as BIOL 375.

EECS 381. Hybrid Systems (3)
Today, the most interesting computer code and microprocessor designs are "embedded" and hence interact with the physical world, producing a mixture of digital and analog domains. The class studies an array of tools for understanding and designing these "hybrid systems." Topics include: basics of language and finite state automata theory, discrete-event dynamic systems, Petri nets, timed and hybrid automata, and hybrid dynamical systems. Simulation, verification, and control concepts and languages for these models. Prereq: MATH 224 and either EECS 246 or MATH 304.

EECS 382. Microprocessor-Based Design (3)
Microprocessor architectures, memory design, timing, polled and interrupt driven I/O, microprocessor support devices, microcontrollers, integrated hardware/software design considerations. Prereq: ENGR 210 and EECS 281.

EECS 383. Microprocessor Applications to Controls (3)
Digital control and its implementation using microprocessors. Z-transforms. Time response characteristics, steady-state error, mapping from the s-plane to the z-plane. Digital controller design-stability testing methods, gain and phase margins, PID controllers, digital filter structures. Prereq: EECS 246 or equivalent.

EECS 385. Engineering in Community Service II (3)
Project-oriented course; students work on "real" engineering projects of benefit to the community and in partnership with community "customers." Project teams consists of a mix of sophomores, juniors, and seniors. Students perform engineering design, project specification, and technical research as appropriate to their technical background. Emphasis on project planning and organization, teamwork, project management, communication skills, customer awareness, and professional responsibility. Prereq: Junior or Senior standing in EECS.

EECS 391. Introduction to Artificial Intelligence (3)
Overview of artificial intelligence, knowledge representation, search, game-playing, logic rule-based systems, AI programming languages, learning, neural networks, evolutionary algorithms, natural language understanding, planning, robotics. Prereq: ENGR 131.
EECS 394X. Senior Project I (3)

EECS 396L. Special Topics (1-6)
(Credit as arranged.) Limited to juniors and seniors.

EECS 396M. Special Topics: Computer Science (1-9)

EECS 396N. Special Topics (1-18)

EECS 397L. Special Topics in Electrical Engineering (1-6)
(Credit as arranged.) Limited to juniors and seniors. Prereq: Consent of instructor.

EECS 398L. Senior Project in Electrical Engineering I (4)

EECS 398M. Software Engineering (3)
Issues in the development of complex software systems. Software lifecycle models. Software engineering methodology, requirements, analysis and specification design implementation, validation, and maintenance. Team development of a significant applications program. Prereq: EECS 337.

EECS 398N. Engineering Projects I (3)
Project experience in the application of course material to practical systems engineering problems. Identification of project, literature review, and proposal preparation for EECS 399.

EECS 399L. Senior Project in Electrical Engineering II (4)
Prereq: EECS 398L (or concur).

EECS 399M. Computer Engineering Design Project (3)
Capstone course for computer engineering seniors. Material from previous and concurrent courses used to solve hardware and/or software design problems. Formal presentations of the projects scheduled during last week of classes.

EECS 399N. Engineering Projects II (3)
Elective projects with emphasis on engineering design. Capstone engineering project. Prereq: EECS 398N.

Graduate Courses

EECS 400T. Graduate Teaching I (0)
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, tutoring students. Prereq: Ph.D. student in EECS department.

EECS 401. Digital Signal Processing (3)
Characterization of discrete-time signals and systems. Fourier analysis: the Discrete-time Fourier Transform, the Discrete-time Fourier series, the Discrete Fourier Transform and the Fast Fourier Transform. Continuous-time signal sampling and signal reconstruction. Digital filter design: infinite impulse response filters, finite impulse response filters, filter realization and quantization effects. Random signals: discrete correlation sequences and power density spectra, response of linear systems. Prereq: EECS 313.

EECS 404. Digital Control Systems (3)
Analysis and design techniques for computer based control systems. Sampling, hybrid continuous-time/discrete-time system modeling; sampled data and state space representations, controllability, observability and stability, transformation of analog controllers, design of deadbeat and state feedback controllers; pole placement controllers based on input/output models, introduction to model identification, optimal control and adaptive control. Prereq: EECS 304.

EECS 405. Data Structures and File Management (3)
Fundamental concepts: sequential allocation, linked allocation, lists, trees, graphs, internal sorting, external sorting, sequential, binary, interpolation search, hashing file, indexed files, multiple level index structures, btrees, hashed files. Multiple attribute retrieval; inverted files, multi lists, multiple-key hashing, hd trees. Introduction to data bases. Data models. Prereq: EECS 233 and MATH 304.

EECS 408. Introduction to Linear Systems (3)
Analysis and design of linear feedback systems using state-space techniques. Review of matrix theory, linearization, transition maps and variations of constants formula, structural properties of state-space models, controllability and observability, realization theory, pole assignment and stabilization, linear quadratic regulator problems, observers, and the separation theorem. Prereq: EECS 304.

EECS 409. Discrete Event Systems (3)
A broad range of system behavior can be described using a discrete event framework. These systems are playing an increasingly important role in modeling, analyzing, and designing manufacturing systems. Simulation, automata, and queuing theory have been the primary tools for studying the behavior of these logically complex systems; however, new methods and techniques as well as new modeling frameworks have been developed to represent and to explore discrete event system behavior. The class will begin by studying simulation, the theory of languages, and finite state automata, and queuing theory approaches and then progress to examining selected additional frameworks for modeling and analyzing these systems including Petrinets, perturbation analysis, and Min-Max algebras.

EECS 410. Ultrasonic Engineering (3)
Acoustical waves in fluids and solids, surface acoustic waves, transmission phenomena, radiators, transducers, filters, flow measurements, pulse echo techniques, flaw detection, sonar, imaging, holography.

EECS 411. Introduction to Logic Programming (3)
Basic constructs of logic programs, terms, facts, rules, queries. Logic programs for manipulating recursive data structures. Unification and the logic programming computation model. How Prolog realized the abstract computational mode. Arithmetic, structure inspection, metalogical and extralogical techniques in Prolog. Advanced programming techniques: nondeterminism, difference structures, DCGS, meta-interpreters. Applications. Prereq: EECS 233.

EECS 412. Electromagnetic Fields III (3)
Maxwell's equations, macroscopic versus microscopic fields, field interaction with materials in terms of polarization vectors P and M. Laplace's and Poisson's equations and solutions, scalar and vector potentials. Wave propagation in various types of media such as anisotropic and gyrotropic media. Phase and group velocities, signal velocity and dispersion. Boundary value problems associated with wave-guide and cavities. Wave solutions in cylindrical and spherical coordinates. Radiation and antennas.

EECS 413. Nonlinear Systems I (3)
This course will provide an introduction to techniques used for the analysis of nonlinear dynamic systems. Topics will include existence and uniqueness of solutions, phase plane analysis of two dimensional systems including Poincare-Bendixson, describing functions for single-input single-output systems, averaging methods, bifurcation theory, stability, and an introduction to the study of complicated dynamics and chaos. Coreq: EECS 408.

EECS 414. Complex Systems Modeling and Analysis (3)
The concept of a complex system as a relationship of identifiable subsystems. Modeling of large-scale systems by aggregation, perturbation, via system identification and by the use of fuzzy logic. The structural properties of large-scale systems. A hierarchical, multi-level approach to large-scale systems analysis and synthesis. Coordination by the interaction balance and by interaction prediction principles. Decentralized decision making and control of large-scale systems. Near optimum system design. Structure and stability of fuzzy control systems.

EECS 415. Integrated Circuit Technology I (3)
Review of semiconductor technology. Device fabrication processing, material evaluation, oxide passivation, pattern transfer technique, diffusion, ion implantation, metallization, probing, packaging, and testing. Design and fabrication of passive and active semi-conductor devices. Prereq: EECS 322.

EECS 416. Optimization Theory and Techniques (3)
Underlying theory of linear, nonlinear, multilevel, and multiobjective optimization. Techniques include linear programming and extensions, quadratic programming, dynamic programming, decomposition coordination schemes for multilevel optimization. Methods for generating Pareto optimal solutions in multiobjective optimization. Applications to engineering problems. Prereq: MATH 201 or equivalent.

EECS 417. Introduction to Stochastic Control (3)
Analysis and design of controllers for discrete-time stochastic systems. Review of probability theory and stochastic properties, input-output analysis of linear stochastic systems, spectral factorization and Weiner filtering, minimum variance control, state-space models of stochastic systems, optimal control and dynamic programming, statistical estimation and filtering, the Kalman-Bucy theory, the linear quadratic Gaussian problem, and the separation theorem. Prereq: EECS 408.

EECS 418. System Identification and Adaptive Control (3)
Parameter identification methods for linear discrete time systems: maximum likelihood and least squares estimation techniques. Adaptive control for linear discrete time systems including self-tuning regulators and model reference adaptive control. Consideration of both theoretical and practical issues relating to the use of identification and adaptive control.

EECS 419. Computer System Architecture (3)
Interaction between computer systems hardware and software. Pipeline techniques - instruction pipelines - arithmetic pipelines. Instruction level parallelism. Cache mechanism. I/O structures. Examples taken from existing computer systems. Prereq: EECS 338.

EECS 420. Solid State Electronics I (3)
Quantum mechanics and solid state physics. Crystal structures, electrons in periodic structures, band structures, transport phenomenon, nonequilibrium process, lattice dynamics, scattering mechanisms, surface and interface physics; physics of semiconductor electronic devices. Prereq: EECS 321.

EECS 421. Optimization of Dynamic Systems (3)
Fundamentals of dynamic optimization with applications to control. Variational treatment of control problems and the Maximum Principle. Structures of optimal systems; regulators, terminal controllers, time-optimal controllers. Sufficient conditions for optimality. Singular controls. Computational aspects. Selected applications. Prereq: EECS 408. Cross-listed as MATH 434.

EECS 422. Solid State Electronics II (3)
Advanced physics of semiconductor devices. Review of current transport and semiconductor electronics. Surface and interface properties. P-N junction. Bipolar junction transistors, field effect transistors, solar cells and photonic devices.

EECS 423. Distributed Systems (3)
Introduction to distributed systems; system models; network architecture and protocols; interprocess communication; client-server model; group communication; TCP sockets; remote procedure calls; distributed objects and remote invocation; distributed file systems; file service architecture; name services; directory and discovery services; distributed synchronization and coordination; transactions and concurrency control; security; cryptography; replication; distributed multimedia systems. Prereq: EECS 338.

EECS 425. Computer Communications Networks (3)
Covers computer network architecture. Topics include: network applications; types of networks; network architecture; OSI, TCP/IP and ATM reference models; transmission media; the telephone system; ISDN and ATM error detection and correction; data link protocols; channel allocation; LAN protocols; bridges; routing; congestion control; internetworking; transport services and protocols; TCP/IP and ATM protocols; socket programming; security; Domain Name System; Simple Network Management Protocol; e-mail, WWW; Java; Corba; distributed multimedia. Prereq: EECS 338.

EECS 426. MOS Integrated Circuit Design (3)
Design of digital and analog MOS integrated circuits. IC fabrication and device models. Logic, memory, and clock generation. Amplifiers, comparators, references, and switched-capacitor circuits. Characterization of circuit performance with/without parasitics using hand analysis and SPICE circuit simulation. Prereq: EECS 344 and EECS 321.

EECS 427. MEMS for Sensing and Communication (3)
This course covers basic MEMS fabrication technologies and device operating principles of MEMS resonators and inertial sensors such as accelerometers and gyroscopes. Critical issues regarding sensing resolution and low noise interface electronics design will be discussed. MEMS applications such as low noise oscillators, filters, switches, etc. for wireless communications will also be covered.

EECS 428. Web Computing (3)
The goal of this course is to acquire expertise in state-of-the-art Web technology, including performance evaluation, servers, caching, security, and search engines. Expected work includes bi-weekly homework assignments (includes small projects), final class project suggested by students, midterm, and final. Coreq: EECS 425 or permission of instructor.

EECS 429. Risk and Reliability Methods for Engineers (3)
Probabilistic models and methods for risk, reliability, and quality engineering; Markov decision processes; stochastic dynamic programming; stochastic programming and other methods for risk analysis; failure models; qualitative fault analysis; reliability analysis of systems; life data analysis and accelerated life testing; design of experiments for quality engineering; statistical quality control; and acceptance sampling for quality control.

EECS 430. Object-Oriented Software Development (3)
Covers advanced methodology for the design of large software systems. Topics include: object-oriented analysis and design; encapsulation; inheritance; subtype and parametric polymorphism; object-oriented program-

ming languages; design patterns; application frameworks; software architecture; user-interfaces; concurrent and distributed objects. Prereq: EECS 337 or consent of instructor.

EECS 431. Software Engineering (3)
Design of software systems working from specifications; top-down decomposition using stepwise refinement; object-oriented methods; prototyping. Software metrics and testing; software quality and reliability; maintenance; human factors. Homework involves working in teams on large software projects. Prereq: EECS 337.

EECS 432. Compiler Construction (3)
Top-down and bottom-up recognizers for context-free grammars; LR(k) parsers, error recovery, semantic analysis, storage allocation for block structured languages, optimization, code generation. Homework involves writing a compiler for a block structured language. Prereq: EECS 337.

EECS 433. Database Systems (3)
Basic issues in file processing and database management systems. Physical data organization. Relational databases. Database design. Relational Query Languages, SQL. Query languages. Query optimization. Database integrity and security. Object-oriented databases. Object-oriented Query Languages, OQL. Prereq: EECS 341 and MATH 304.

EECS 434. Microfabricated Silicon Electromechanical Systems (3)
Topics related to current research in microelectromechanical systems based upon silicon integrated circuit fabrication technology: fabrication, physics, devices, design, modeling, testing, and packaging. Bulk micromachining, surface micromachining, silicon to glass and silicon-silicon bonding. Principles of operation for microactuators and microcomponents. Testing and packaging issues. Prereq: EECS 322 or EECS 415.

EECS 435. Data Mining (3)
Data Mining is the process of discovering interesting knowledge from large amounts of data stored either in databases, data warehouses, or other information repositories. Topics to be covered includes: Data Warehouse and OLAP technology for data mining, Data Preprocessing, Data Mining Primitives, Languages, and System Architectures, Mining Association Rules from Large Databases, Classification and Prediction, Cluster Analysis, Mining Complex Types of Data, and Applications and Trends in Data Mining. Prereq: EECS 341 or equivalent.

EECS 436. Advances in Databases (3)
Advanced topics in databases will be covered in this course. Query optimization in object-oriented databases, temporal databases, issues in multimedia databases, databases and Web, graphical query interfaces. Basic knowledge in databases is required. Prereq: EECS 433.

EECS 437. Optical Communication (3)
In this course, suitable for graduate students or advanced undergraduates interested in photonics, a broad range of topics will be covered in the field of optical communication, with an aim to provide a sophisticated perspective of current technology and trends in optical communication components, systems, and networks. Prereq: EECS 309.

EECS 438. Biomedical Microdevices (3)
Topics related to current research in Microelectromechanical systems (MEMS) technology for biomedical applications. Review of fabrication technologies for semiconductor and plastic materials, microscale transport behavior, biocompatibility and materials issues, microfluidic devices for biochemical analysis, miniaturized sensors and actuators for implantable medical instrumentation, and microstructures for tissue engineering.

EECS 440. Automata and Formal Languages (3)
(See MATH 410.) Cross-listed as MATH 410.

EECS 445. Formal Verification (3)
Introduction and survey of principles and methodologies in formal specification and verification of systems (hardware, software, hybrid). Prereq: EECS 345 or graduate standing.

EECS 450. Production and Operations Systems (3)
Fundamental theories and techniques, decision making, and artificial intelligence for solving production/manufacturing problems. Formulation, modeling, planning, and control of production problems at three levels: strategic, tactical, and operational (long term, medium, and short term). Specific problems include aggregate planning, project planning, scheduling, line balancing, sequencing, and machine set-up. Special emphasis will be given on decomposition and control of computer integrated systems, on-line and off-line supervisory planning, and man/machine systems.

EECS 452. Random Signals (3)
Fundamental concepts in probability. Probability distribution and density functions. Random variables, functions of random variables, mean, variance, higher moments, Gaussian random variables, random processes, stationary random processes, and ergodicity. Correlation functions and power spectral density. Orthogonal series representation of colored noise. Representation of bandpass noise and application to communication systems. Application to signals and noise in linear systems. Introduction to estimation, sampling, and prediction. Discussion of Poisson, Gaussian, and Markov processes.

EECS 454. Analysis of Algorithms (3)
This course presents and analyzes a number of efficient algorithms. Problems are selected from such problem domains as sorting, searching, set manipulation, graph algorithms, matrix operations, polynomial manipulation, and fast Fourier transforms. Through specific examples and general techniques, the course covers the design of efficient algorithms as well as the analysis of the efficiency of particular algorithms. Certain important problems for which no efficient algorithms are known (NP-complete problems) are discussed in order to illustrate the intrinsic difficulty which can sometimes preclude efficient algorithmic solutions. Prereq: MATH 304 and (EECS 340 or EECS 405). Cross-listed as OPRE 454.

EECS 455. Wireless Communications (3)
Cellular telephone systems, wireless networks, receiver architectures, noise characterization, error-correction coding, digital modulation, multiple-access technologies, multipath fading. Prereq: STAT 332 and EECS 351 or consent of instructor.

EECS 456. Microwave Engineering (3)
Transmission line theory, propagation in waveguides, coaxial lines, striplines. Circuit theory of microwave systems, multi-port circuits, equivalent circuits. Foster's Reactance Theorem. Scattering matrix. Smith Charts, impedance matching and transformation using stub tuners and transformers. Electromagnetic resonators. Prereq: EECS 412.

EECS 458. Introduction to Bioinformatics (3)
Fundamental algorithmic methods in computational molecular biology and bioinformatics discussed. Sequence analysis, pairwise and multiple alignment, probabilistic models, phylogenetic analysis, folding and structure prediction emphasized. Prereq: EECS 340, EECS 233.

EECS 459X. Domain Theoretic Methods for Artificial Intelligence (3)
(See EECS 358.) Cross-listed as MATH 450.

EECS 460. Manufacturing, Design, and Automated Systems (3)
The course is designed primarily for graduate engineering students who wish to know about the fundamentals and modeling of production/automation/manufacturing systems. The course provides a survey of various topics in production automation and computer-aided and integrated manufacturing with emphasis on decision making, optimization, and modeling. Topics include computerized process planning, on-line and off-line supervisory computer control, computerized discrete production systems, numerical control, monitoring and planning, flexible manufacturing systems, group technology, materials handling systems, man/machine systems and requirements, design and analysis of assembly systems, and computerized facility layout design problems. The course presents a step-by-step and cohesive account of concepts, theories, and procedures for solving modern manufacturing and production problems with emphasis on computer applications. Prereq: Consent of instructor.

EECS 462. Research Topics in Lasers and Optics (3)
Topics related to current research, e.g., laser theory, coherent optics, optical information processing.

EECS 463. Techniques of Model-based Control (3)
Strategies of process control centered around the use of process models in the control system. Topics include single loop, feed forward, cascade and multivariable internal model control. Tuning controllers to accommodate process uncertainty. Treatment of control effect and output constraints in model predictive control and modular-multivariable control. Prereq: EECS 304. Cross-listed as ECHE 463.

EECS 466. Computer Graphics (3)
Theory and practice of computer graphics: object and environment representation including coordinate transformations image extraction including perspective, hidden surface, and shading algorithms; and interaction. Covers a wide range of graphic display devices and systems with emphasis in interactive shaded graphics. Laboratory. Prereq: EECS 233.

EECS 473. Multimedia and Web Computing (3)
Multimedia is an important application area that will be at the center for next-generation computer systems and software design. It is a fast-changing technology, and, already, in the industry, there is a significant demand for computer scientists/engineers with multimedia system design knowledge. The objective of EECS 473 is to present design issues for multimedia systems from specification to software implementation and testing. This will include multimedia basics, data capture/models/compression, synchronization models, multimedia servers, OS support for multimedia, multimedia communication systems, and multimedia user interfaces. There will be a project about designing and implementing a multimedia system. Students are expected to know Unix systems programming (System V IPCs, fork, exec, etc.), RPC, thread and socket programming. Prereq: ENGR 131, EECS 233, and EECS 338.

EECS 475. Autonomous Robotics (3)
Introduction to the design, construction and control of autonomous mobile robots. The first half of the course consists of focused exercises on mechanical construction with LEGO, characteristics of sensors, motors and batteries, and control strategies for autonomous robots. In the second half of the course, students design, build and program their own complete robots that participate in a public competition. All work is performed in groups. Biologically-inspired approaches to the design and control of autonomous robots are emphasized throughout. Prereq: Consent of instructor. Cross-listed as BIOL 475.

EECS 477. The Dynamics of Adaptive Behavior (3)
Introduction to embodied, situated, and dynamical approaches to the design and analysis of autonomous agents and animals. Topics include recurrent neural networks, coupled neural/body/environment systems, and evolution and analysis of neural circuits. Behavior studied include examples from motor control, perception, learning, and cognition. Prereq: ENGR 131 and MATH 224. Cross-listed as BIOL 477.

EECS 478. Computational Neuroscience (3)
Computer simulation of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural circuits, as well as to cable theory, passive and active compartmental modeling, numerical integration methods, models of plasticity and learning, models of brain systems, and their relationship to artificial neural networks. Term project required. Two lectures per week. Cross-listed as BIOL 478, EBME 478, and NEUR 478.

EECS 479. Seminar in Computational Neuroscience (3)
Readings and discussion in the recent literature on computational neuroscience, adaptive behavior, and other current topics. Cross-listed as BIOL 479.

EECS 483. Data Acquisition and Control (3)
Data acquisition (theory and practice), digital control of sampled data systems, stability tests, system simulation digital filter structure, finite word length effects, limit cycles, state-variable feedback and state estimation. Laboratory includes control algorithm programming done in assembly language.

EECS 484. Computational Intelligence I: Basic Principles (3)
This course is concerned with learning the fundamentals of a number of computational methodologies which are used in adaptive parallel distributed information processing. Such methodologies include neural net computing, evolutionary programming, genetic algorithms, fuzzy set theory, and "artificial life." These computational paradigms complement and supplement the traditional practices of pattern recognition and artificial intelligence. Functionalities covered include self-organization, learning a model or supervised learning, optimization, and memorization.

EECS 485. VLSI Systems (3)
Basic MOSFET models, inverters, steering logic, the silicon gate, nMOS process, design rules, basic design structures (e.g., NAND and NOR gates, PLA, ROM, RAM), design methodology and tools (spice, N.mpc, Caesar, mkpla), VLSI technology and system architecture. Requires project and student presentation, laboratory.

EECS 486. Research in VLSI Design Automation (3)
Research topics related to VLSI design automation such as hardware description languages, computer-aided design tools, algorithms and methodologies for VLSI design for a wide range of levels of design abstraction, design validation and test. Requires term project and class presentation.

EECS 487. Computational Intelligence II (3)
This course is concerned with the combined use of the methods of computational intelligence in the performance of complex real-world tasks. Tasks considered include learning models of 'opaque' systems, design and operation of fuzzy control systems, neural-net computing control of systems, optimal control, adaptive learning of time-variant time series, data compression, classification, self-organization of objects into categories, inductive reasoning, decision-making interpretation of signal and images. Prereq: EECS 484.

EECS 488. Embedded Systems Design (3)
Objective: to introduce and expose the student to methodologies for systematic design of embedded system. The topics include, but are not limited to, system specification, architecture modeling, component partitioning, estimation metrics, hardware software codesign, diagnostics.

EECS 489. Robotics I (3)
(See EMAE 489.) Prereq: EMAE 181. Cross-listed as EMAE 489.

EECS 490. Computer Processing of Images (3)
Introduction of computer vision methodologies. Includes the images systems: optics and detectors and geometric relationships between scene and image, 3-D scene scanning and imaging techniques including stereovision and laser rangefinders. Digital signal processing in 2-D and optical preprocessing of images. Real-time digital signal transmission of dynamic images and HDTV. Hardware issues in processing of vision information. Prereq: EECS 246 or equivalent or consent of instructor.

EECS 491. Intelligent Systems I (3)
Artificial intelligence and programming techniques used in design and implementation of intelligent systems. Problem solving and game playing by computer, different representation of problems and games, and their associated solution methods. Knowledge representation: logic, semantic networks frames. Programming in LISP and Prolog.

EECS 500. EECS Colloquium (0)
Seminars on current topics in Electrical Engineering and Computer Science.

EECS 500T. Graduate Teaching II (0)
This course will provide the Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities: grading homeworks, quizzes, and exams, having office hours for students, running recitation sessions, providing laboratory assistance. Prereq: Ph.D. student in EECS department.

EECS 515. Decision Theory with Applications (3)
Fundamentals of decision theory and analysis of decision processes in systems. Elementary decision analysis. Single and multiattribute utility theory under both certainty and uncertainty. Bayesian decision analysis. Sequential decision processes including dynamic programming and Markov processes. Analysis of multi-person decision processes and game theory as related to management decisions. Applications to large-scale systems and to decision support systems.

EECS 516. Large Scale Optimization (3)
Concepts and techniques for dealing with large optimization problems encountered in designing large engineering structure, control of interconnected systems, pattern recognition, and planning and operations of

complex systems; partitioning, relaxation, restriction, decomposition, approximation, and other problem simplification devices; specific algorithms; potential use of parallel and symbolic computation; student seminars and projects. Prereq: EECS 416.

EECS 518. Nonlinear Systems: Analysis and Control (3)
Mathematical preliminaries: differential equations and dynamical systems, differential geometry and manifolds. Dynamical systems and feedback systems, existence and uniqueness of solutions. Complicated dynamics and chaotic systems. Stability of nonlinear systems: input-output methods and Lyapunov stability. Control of nonlinear systems: gain scheduling, nonlinear regulator theory and feedback linearization. Prereq: EECS 408 and EECS 421.

EECS 519. Differential Geometric Nonlinear Control (3)
This advanced course focuses on the analysis and design of nonlinear control systems, with special emphasis on the differential geometric approach. Differential geometry has proved to be an extremely powerful tool for the analysis and design of nonlinear systems, similar to the roles of the Laplace transformation and linear algebra in linear systems. The objective of the course is to present the major methods and results of nonlinear systems and provide a mathematical foundation, which will enable students to follow the recent developments in the constantly expanding literature. This course will also benefit those students from Electrical, Mechanical, Chemical and Biomedical Engineering, who are doing research in the fields that involve nonlinear control problems. Prereq: EECS 408 or equivalent.

EECS 523. Multiobjective and Hierarchical Systems (3)
This course covers basic concepts of hierarchical, multi-level systems, Lagrangian decompositions, and coordination principles. Fundamentals and recent advances in theory, methodology and applications of multiple criteria decision making (MCDM) with single and multiple decision makers are included as are: interactive MCDM methods; multiple objectives for discrete and continuous models; multi-objective programming methods, hierarchical overlapping coordination with single and multiple objectives; multi-objective, multi-stage impact analysis; and applications to large-scale systems and to decision support systems. Cross-listed as OPRE 523.

EECS 526. Integrated Mixed-Signal Systems (3)
Mixed-signal (analog/digital) integrated circuit design. D-to-A and A-to-D conversion, applications in mixed-signal VLSI, low-noise and low-power techniques, and communication sub-circuits. System simulation at the transistor and behavioral levels using SPICE. Class will design a mixed-signal CMOS IC for fabrication by MOSIS. Prereq: EECS 426.

EECS 527. Advanced Sensors: Theory and Techniques (3)
Sensor technology with a primary focus on semiconductor-based devices. Physical principles of energy conversion devices (sensors) with a review of relevant fundamentals: elasticity theory, fluid mechanics, silicon fabrication and micromachining technology, semiconductor device physics. Classification and terminology of sensors, defining and measuring sensor characteristics and performance, effect of the environment on sensors, predicting and controlling sensor error. Mechanical, acoustic, magnetic, thermal, radiation, chemical and biological sensors will be examined. Sensor packaging and sensor interface circuitry. Prereq: EECS 322 or EECS 415 and EECS 434.

EECS 531. Computer Vision (3)
Geometric optics, ray matrics, calibration of monocular and stereo imaging systems. Adaptive camera thresholding and image segmentation, morphological and convolutional image processing. Selected topics including edge estimation and industrial inspection, optimal filtering, model matching, CAD-based vision and range image processing. Neural-net image processing. Model-based computer vision for scene interpretation and autonomous systems. Prereq: EECS 490 or equivalent.

EECS 550. Neuromechanics Seminar (0)
(See EBME 550.) Cross-listed as EBME 550.

EECS 583. Implementation of Non-linear Control (3)
Nonlinear control with emphasis on applications. Basic theory including describing functions, equivalent gains, and Lyapunov stability. Emphasis on digital implementation of nonlinear controllers for high performance applications such as servomechanisms, manipulators, and aerospace systems. Comparison of nonlinear and linear designs. Laboratory experiments and CAD tools for controller performance verification.

EECS 589. Robotics II (3)
Survey of research issues in robotics. Force control, visual servoing, robot autonomy, on-line planning, high-speed control, man/machine interfaces, robot learning, sensory processing for real-time control. Primarily a project-based lab course in which students design real-time software executing on multi-processors to control an industrial robot. Prereq: EECS 489.

EECS 591. Intelligent Systems II (3)

EECS 600. Special Topics (1-18)

EECS 600T. Graduate Teaching III (0)
This course will provide Ph.D. candidate with experience in teaching undergraduate or graduate students. The experience is expected to involve direct student contact but will be based upon the specific departmental needs and teaching obligations. This teaching experience will be conducted under the supervision of the faculty member who is responsible for the course, but the academic advisor will assess the educational plan to ensure that it provides an educational experience for the student. Students in this course may be expected to perform one or more of the following teaching related activities running recitation sessions, providing laboratory assistance, developing teaching or lecture materials presenting lectures. Prereq: Ph.D. student in EECS department.

EECS 601. Independent Study (1-18)

EECS 602. Advanced Projects Laboratory (1-18)

EECS 620. Special Topics (1-18)

EECS 621. Special Projects (1-18)

EECS 649. Project M.S. (1-9)

EECS 651. Thesis M.S. (1-18)

EECS 701. Dissertation Ph.D. (1-18)

EECS 702. Appointed Dissertation Fellow (9)

Degree Program in Engineering, Undesignated

312 Glennan Building (7220)
Phone 216-368-6482; Fax 216-368-6939
James D. Cawley, Associate Dean
e-mail jxc41@po.cwru.edu

The Undesignated Engineering program prepares students who seek a technological background but do not wish to pursue pure engineering careers. For example, some needs in the public sector, such as pollution remediation, transportation, low-cost housing, elective medical care, and crime control could benefit from engineering expertise. To prepare for careers in fields that address such problems, the Undesignated Engineering program allows students to acquire some engineering background, and combine it with a minor in such programs as management, history of technology and science, or economics.

Undergraduate Program

A student electing an undesignated degree must submit both a proposed course schedule and a clear statement of career goals and of the way in which the proposed program will meet those goals. These documents are to be submitted to the office of the associate dean for undergraduate programs of The Case School of Engineering. The program must be approved by the dean of engineering or designate in consultation with representatives of the major and minor departments. A total of at least 128 semester credits are required for graduation.

Since each student's program is unique, no typical curriculum can be shown. Every program must fulfill the requirements described below.

1. Engineering Core
2. A minimum of two engineering electives courses selected from two of the following four groups
   a. Thermodynamics or Physical Chemistry (EMAE 150, EMAC 171 and 172, CHEM 301 and 302, or ECHE 363)
   b. Signals, systems or control (EECS 212, EECS 304, ECHE 367)
   c. Materials science (EMSE 201, EMAC 270, EMSE 314, EBME 306, or EECS 321)
   d. Economics, production systems or decision theory (EECS 350, EECS 352, OPRE 345)

Major

The major must contain a minimum of 24 semester credit hours of work in one of the following engineering fields

- Biomedical engineering
- Chemical engineering
- Civil engineering
- Computer engineering
- Electrical engineering
- Fluid and thermal engineering sciences
- Materials science and engineering
- Polymer science and engineering
- Systems and control engineering

This work includes a senior projects laboratory (3 credits) and usually a course with a physical measurements laboratory.

Minor

The minor program requires a minimum of 15 semester credit hours. Suggested minors for students pursuing the undesignated degree program in engineering are the following. Other minors are available with approval of the Office of Undergraduate Studies.

Engineering

A minor program may be chosen in any engineering field that differs from the major and that, when combined with the major, fulfills a specific purpose or career plan. The purpose of a minor program is to allow more breadth, with less depth in any one engineering area. For example, such a program may appeal to the student who prefers a broad design-oriented background or the student who wishes to couple knowledge in systems and control

Bachelor of Science in Engineering Degree Major in Engineering (Undesignated)

Freshman Year

Fall	Class-Lab-Credit Hours
Open elective or Humanities/Social Science [a]	(3-0-3)
CHEM 111 Principles of Chemistry for Engineers	(4-0-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
ENGL 150 Expository Writing	(3-0-3)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(16-5-17)**

Spring	
Humanities/Social Science or open elective [a]	(3-0-3)
ENGR 145 Chemistry of Materials	(4-0-4)
MATH 122 Calculus for Science and Engineering II	(4-0-4)
PHED 102 Physical Education Activities	(0-3-0)
PHYS 121 General Physics I	(4-0-4)
Total	**(15-3-15)**

Sophomore Year

Fall	
Humanities or Social Science Sequence I	(3-0-3)
ENGR 200 Statics and Strength of Materials	(3-0-3)
MATH 223 Calculus for Science and Engineering III	(3-0-3)
ECES 251 Numerical Methods	(2-2-3)
PHYS 122 General Physics II	(4-0-4)
Total	**(15-2-16)**

Spring	
Humanities or Social Science Sequence II	(3-0-3)
ENGR 225 Thermodynamics, Fluid Mechanics, Heat and Mass Transfer	(4-0-4)
ENGR 210 Introduction to Circuits and Instrumentation	(3-2-4)
MATH 224 Elementary Differential Equations	(3-0-3)
PHYS 221 General Physics III, Modern Physics	(3-0-3)
Total	**(16-2-17)**

Junior Year

Fall	Class-Lab-Credit Hours
Humanities or Social Science Sequence III	(3-0-3)
Major Concentration Course	(3-0-3)
Major Concentration Course	(3-0-3)
Minor Concentration Course	(3-0-3)
Engineering elective	(3-0-3)
Open elective	(3-0-3)
Total	**(18-0-18)**

Spring	
ENGL 398N Professional Communications	(3-0-3)
Major Concentration Course	(3-0-3)
Major Concentration Course	(3-0-3)
Minor Concentration Course	(3-0-3)
Engineering elective	(3-0-3)
Total	**(15-0-15)**

Senior Year

Fall	
Humanities or Social Science elective	(3-0-3)
Exxx 398 Engineering Senior Project	(0-6-3)
Major Concentration Course	(3-0-3)
Minor Concentration Course	(3-0-3)
Minor Concentration Course	(3-0-3)
Total	**(12-6-15)**

Spring	
Humanities or Social Science elective	(3-0-3)
Major Concentration Course	(3-0-3)
Major Concentration Course	(3-0-3)
Minor Concentration Course	(3-0-3)
Open elective	(3-0-3)
Total	**(15-0-15)**

Hours required for graduation: 128

a. One of these courses must be a humanities/social science course.

engineering with knowledge in a field such as civil engineering, chemical processing, or computer engineering. Other major and minor combinations that may be of interest are the coupling of a civil engineering major with a metallurgy or materials minor or a combination of electrical and materials science and engineering.

Science

A minor field may be chosen in any field of science wherein the major-minor combination fulfills a unique purpose. Many engineering majors and science minors can be successfully combined. For example, a major in civil engineering coupled with a minor in geology leads to a program aimed at geophysical sciences or oceanography. The student with electrical engineering interests in lasers, optics, solid state, plasmas, and the like may profit by coupling an electrical engineering major with a physics minor. In particular, an engineering major coupled with a minor in biological sciences or in biomedical engineering (plus chemistry) leads to a biomedical engineering background for the student interested in pre-medicine, pre-dentistry, pre-nursing, or pre-biomedical engineering. This combination also provides a unique background for a student interested in biomaterials or a student who wishes to explore the bioelectronics area or biomechanics, systems biology, or a combination that deals with information processing and the computer in biomedical applications.

Management

Many students enter the engineering program at Case Western Reserve in preparation for industrial management careers. Generally, their plan is to work in an engineering capacity and gradually assume management responsibilities. Some of these students plan to take a graduate program in management, such as the Master of Business Administration degree. However, others rely on a combination of undergraduate elective courses, job experience, and industrial training programs for this career preparation.

To serve engineering students whose career goals involve management, a minor program has been developed in cooperation with the Weatherhead School of Management. This program gives the student the options of direct entry into industry in either an engineering or a management tracking program or entry into graduate school to earn the Master of Science degree in engineering or the Master of Business Administration degree.

A management minor requires the following courses

- ACCT 303, Survey of Accountancy (3)
- BAFI 355, Corporation Finance (3)
- OPMT 350, Operations Management (3)

plus any two of the following

- LHRP 251, Industrial Relations and Administrative Practices (or LHRP 311, Labor Problems (3))
- MIDS 308, Management Information Systems I (3)
- MKMR 301, Marketing Management(3)
- OPRE 201, Introduction to Operations Research I (3)
- ORBH 250, Introduction to Organizational Behavior and Management (3)

History of Technology and Science

The purpose of coupling an engineering major with a minor in the history of technology and science is primarily to prepare for entry into the field of history of technology. Beyond this, however, knowledge of the history of technology may be invaluable to engineers who take decision-making roles during their careers. This minor provides a much needed emphasis on the consequences of technology and technological decisions on society and the importance of historical insight in such decisions.

The minor program can be tailored to individual interests, based on the following offerings

- HSTY 266, The Engineer in America (3)
- HSTY 306, Engineering in History (3)
- HSTY 307, Development of Chemistry and Chemical Engineering (3)
- HSTY 366, Science, Technology, and Government (3)
- HSTY 377, Nuclear Weapons and Arms Control (3)

Economics

The field of economics is moving rapidly toward a more quantitative approach and is an important field for engineers. The economics minor requires the following courses

- ECON 103, Principles of Macroeconomics (3)
- ECON 102, Principles of Microeconomics (3)

The following electives in economics are suggested

- ECON 341, Money and Banking (3)
- ECON 326, Econometrics (3)
- ECON 342, Public Finance (3)
- ECON 369, Economics of Industrial Production and Technology (3)
- ECON 386, Urban Economics (3)
- ECON 361, Managerial Economics (3)

Engineering Physics

Rockefeller Building (7079)
Phone 216-368-4017; Fax 216-368-4671
Kenneth D. Singer
e-mail kds4@po.cwru.edu

The engineering physics major allows students with strong interests in both physics and engineering to concentrate their studies in the common areas of these disciplines. The engineering physics major prepares students to pursue careers in industry, either directly after undergraduate studies, or following graduate study in engineering or physics. Many employers value the unique problem solving approach of physics, especially in industrial research and development.

Students majoring in engineering physics complete the Engineering Core as well as a rigorous course of study in physics. Students select a concentration area from an engineering discipline, and must complete a sequence of at least four courses in this discipline. In addition, a senior research project under the guidance of a faculty member in the concentration discipline is required. The project includes a written report and participation in the senior symposium.

Details of the engineering physics program can be found under the department of Physics in the College of Arts and Sciences section.

Department of Macromolecular Science and Engineering

314 Kent Smith Building (7202)
Phone 216-368-4172; Fax 216-368-4202
Alexander Jamieson, Chair
e-mail amj@po.cwru.edu
http://www.scl.cwru.edu/cse/emac

Macromolecular science and engineering is the study of the synthesis, structure, processing, and properties of polymers. These giant molecules are the basis of synthetic materials including plastics, fibers, rubber, films, paints, membranes, and adhesives. Research is constantly expanding these applications through the development of new high performance polymers, e.g. for engineering composites, electronic, optical, and biomedical uses. In addition, most biological systems are composed of macromolecules—proteins (e.g. silk, wool, tendon), carbohydrates (e.g. cellulose) and nucleic acids (RNA and DNA) can all be classified as polymers and are studied by the same methods that are applied to synthetic polymers.

Production of polymers and their components is central to the chemical industry, and statistics show that over 75 percent of all chemists and chemical engineers in industry are involved with some aspect of polymers. Despite this, formal education in this area is offered by only a few universities in this country, resulting in a continued strong demand for our graduates upon completion of their B.S., M.S., or Ph.D. degrees.

Faculty

Alexander M. Jamieson, D. Phil. (Oxford University, England)
Professor and Chair
Laser light scattering; rheology and transport of macromolecules in solution and bulk; positron annihilation lifetime studies of free volume in polymers; structure-function relationships of biological macromolecules.

Eric Baer, D. Eng. (The Johns Hopkins University)
The Herbert Henry Dow Professor of Science and Engineering
Irreversible microdeformation mechanisms; pressure effects on morphology and mechanical properties; relationships between hierarchical structure and mechanical function; mechanical properties of soft connective tissue; polymer composites and blends; polymerization and crystallization on crystalline surfaces; viscoelastic properties of polymer melts; damage and fracture analysis of polymers and their composites. Structure-property relationships in biological systems

Bachelor of Science in Engineering Degree Major in Engineering Physics

Freshman Year — Class-Lab-Credit Hours

Fall

CHEM 111 Principles of Chemistry for Engineers	(4-0-4)
CHEM 113 Principles of Chemistry Laboratory	(1-3-2)
MATH 121 Calculus for Science and Engineering I[a]	(4-0-4)
PHYS 121 General Physics I. Mechanics[b]	(4-3-4)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(16-9-17)**

Spring

MATH 122 Calculus for Science and Engineering IIa	(4-0-4)
PHYS 122 General Physics II. Electricity & Magnetism[b]	(4-3-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
ENGR 145 Chemistry of Materials	(4-0-4)
PHED 102 Physical Education Activities	(0-3-0)
Total	**(14-8-15)**

Sophomore Year

Fall

MATH 223 Calculus for Science & Engineering III[a]	(3-0-3)
PHYS 221 General Physics III – Modern Physics	(3-0-3)
ENGR 200 Statics and Strength of Materials	(3-0-3)
ENGR 210 Circuits & Instrumentation	(3-2-4)
Humanities/Social Science Elective	(3-0-3)
Total	**(15-2-16)**

Spring

MATH 224 Differential Equations[a]	(3-0-3)
PHYS 208 Instrumentation and Signal Analysis Lab	(2-4-4)
PHYS 250 Mathematics, Physics and Computing	(3-0-3)
PHYS 310 Classical Mechanics	(3-0-3)
ENGR 225 Thermodynamics, Fluids, Heat & Mass Transfer	(4-0-4)
Total	**(15-4-17)**

Junior Year — Class-Lab-Credit Hours

Fall

PHYS 313 Thermodynamics and Statistical Mechanics	(3-0-3)
PHYS 317 Engineering Physics Lab I	(2-4-4)
PHYS 331 Introduction to Quantum Mechanics I	(3-0-3)
Engineering Concentration[c]	(3-0-3)
Humanities/Social Science Elective	(3-0-3)
Total	**(14-4-16)**

Spring

PHYS 318 Engineering Physics Lab II	(2-4-4)
PHYS 324 Electricity and Magnetism I	(3-0-3)
ENGL 398N Professional Communications	(3-0-3)
Humanities/Social Science Sequence I	(3-0-3)
Engineering Concentration[c]	(3-0-3)
Total	**(14-4-16)**

Senior Year

Fall

PHYS 315 Introduction to Solid State Physics	(3-0-3)
PHYS 325 Electricity and Magnetism II	(3-0-3)
PHYS 353 Senior Engineering Physics Project	(0-6-3)
Engineering Concentration[c]	(3-0-3)
Humanities/Social Science Sequence II	(3-0-3)
Total	**(12-6-15)**

Spring

PHYS 353 Senior Engineering Physics Project	(0-6-3)
Applied Quantum Mechanics[d]	(3-0-3)
Engineering Concentration[c]	(3-0-3)
Humanities/Social Science Elective	(3-0-3)
Humanities/Social Science Sequence III	(3-0-3)
Total	**(12-6-15)**

Hours required for graduation: 127

a. Selected students may be invited to take MATH 123, 124, 227, and 228 in place of MATH 121, 122, 223, and 224.
b. Selected students may be invited to take PHYS 123, 124 Physics and Frontiers I, II Honors in place of PHYS 121, 122.
c. Engineering Physics Concentration courses are flexible, but must be in a specific engineering discipline or study area and be approved by an advisor. Possible concentration areas include: Aerospace engineering, Biomedical engineering "hardware," Biomedical engineering "software," Chemical engineering, Civil engineering (solid mechanics, structural and geotechnical, environmental), Computer science, Computer systems hardware, Computer systems software, Control systems and automation, Electrical engineering, Macromolecular science, Materials science and engineering, Mechanical engineering, Signal processing, Systems analysis and decision making.
d. PHYS 322, EEAP 321, EEAP 420, EMSE 314, or EMSE

John Blackwell, Ph.D. (University of Leeds, England)
Leonard Case Jr. Professor
Determination of the solid state structure and morphology of polymers. X-ray analysis of the structure of thermotropic copolyesters, copolyimides, polyurethanes, polysaccharides; supramolecular assemblies, fluoropolymers; molecular modeling of semi-crystalline and liquid crystalline polymers; rheological properties of polysaccharides and glycoproteins.

Elena Dormidontova, Ph.D. (Moscow State University)
Assistant Professor
Statistical physics of macromolecules, phase behavior (phase stability and thermodynamic ordering) and properties of complex polymer and biopolymer systems: biocompatible and water-soluble polymers (their properties and applications for biomimetics and drug delivery), hydrogen bonded and associating polymers (reversibly associated living polymers), polymer/surfactant systems, polymer micelles (at thermodynamic equilibrium and micellization kinetics), polyelectrolytes and block copolymers.

Anne Hiltner, Ph.D. (Oregon State University)
Professor
Structure-property relationships; irreversible deformation, crack propagation and fracture of polymers, blends and composites; microlayer processing of polymers; structure-function relationships in collagenous tissues; biostability of biomaterials.

Hatsuo Ishida, Ph.D. (Case Western Reserve University)
Professor
Processing of polymers and composite materials; structural analysis of surfaces and interfaces; molecular spectroscopy of synthetic polymers.

Jack L. Koenig, Ph.D. (University of Nebraska, Lincoln)
The Donnell Institute Professor
Polymer structure-property relationships using infrared, Raman, NMR spectroscopy and spectroscopic imaging techniques

Jerome B. Lando, Ph.D. (Polytechnic Institute of Brooklyn)
Professor
Solid state polymerization; X-ray crystallography of polymers; electrical properties of polymers; ultra-thin polymer films.

Morton Litt, Ph.D. (Polytechnic Institute of Brooklyn)
Professor
Kinetics and mechanisms of free radical and ionic polymerization; mechanical properties of polymers; fluorocarbon chemistry; synthesis of novel monomers and polymers; polymer electrical properties; cross-linked liquid crystal polymers

Ica Manas-Zloczower, D.Sc. (Israel Institute of Technology)
Professor
Structure and micromechanics of fine particle clusters; interfacial engineering strategies for advanced materials processing; dispersive mixing mechanisms and modeling; design and mixing optimization studies for polymer processing equipment through flow simulations

Sergei Nazarenko, Ph.D. (Academy of Sciences, Moscow)
Assistant Professor
Diffusion and transport properties of polymeric materials; barrier structures; macromolecular interdiffusion; non-equilibrium behavior of polymer glasses.

Stuart Rowan, Ph.D. (University of Glasgow, UK)
Assistant Professor
Organic chemistry, synthesis, supramolecular chemistry, conducting polymers, interlocked macromolecules (polyrotaxanes and polycatenanes), peptide nucleic acids, supramolecular polymerization, reversible 'dynamic' chemistry and combinatorial libraries.

David Schiraldi, Ph.D. (University of Oregon)
Associate Professor
Monomer and polymer synthesis, structure-property relationships, nanocomposites, polymerization catalysis, combinatorial synthesis and testing of polymers, synthetic fibers, barrier packaging materials.

Christoph Weder, Ph.D. (ETH Zurich, Switzerland)
Associate Professor
Design, synthesis, structure-property relationship and application of novel functional polymer systems; advanced optical applications of polymers; anisotropic polymer systems; novel polymers for thin film and fiber applications.

Emeriti Faculty

Charles E. Rogers, Ph.D. (Syracuse University and State University of New York)
Emeritus Professor
Transport and mechanical properties of polymers; synthesis and properties of multicomponent systems; environmental effect on polymers; adhesion, adhesives, and coatings.

Robert Simha, Ph.D. (University of Vienna)
Emeritus Professor
Hydrodynamics of colloidal suspensions. Viscosity and thermodynamics of polymer solutions. Chemical kinetics and statistics of synthetic and biological macromolecules. Statistical thermodynamics and the thermal and pressure properties of polymer melt, glass and crystal. Phase equilibria in polymer mixtures. The glassy state—steady state and relaxational properties.

Secondary Faculty

James M. Anderson, Ph.D. (Oregon State University), M.D. (Case Western Reserve University)
Professor of Macromolecular Science, Pathology, and Biomedical Engineering
Development of polymers for medical and dental applications

Donald Feke, Ph.D. (Princeton University)
Professor of Chemical Engineering, and Macromolecular Science
Fine-particle processing; colloidal phenomena; dispersive mixing; acoustic separation methods

LeRoy Klein, Ph.D. (Boston University), M.D. (Case Western Reserve University)
Professor of Orthopaedics, Biochemistry
Collagen physiology

J. Adin Mann, Jr., Ph.D. (Iowa State University)
Professor of Chemical Engineering
Surface phenomena; interfacial dynamics; light scattering; stochastic processes of adsorption and molecular rearrangement at interfaces

Roger Marchant, Ph.D. (Case Western Reserve University)
Professor of Biomedical Engineering
Biopolymers; polymer surface coatings; properties and characterization of polymer surfaces on implants and sensors

Syed Qutubuddin, Ph.D. (Carnegie-Mellon University)
Professor of Chemical Engineering
Colloids; polymers and interfacial phenomena; laser light scattering; enhanced oil recovery

Charles Rosenblatt, Ph.D., (Harvard University)
Professor of Physics
Experimental condensed matter physics; liquid crystal physics

Kenneth Singer, Ph.D., (University of Pennsylvania)
Professor of Physics
Nonlinear optical properties of polymers; contributions of molecular order to the nonlinear optical response in polymers; optical probes of polymer relaxation; formation of and propagation of light in polymer waveguides.

Masood Tabib-Azar (Rensselaer Polytechnic Institute)
Associate Professor of Electrical, Systems, Computer Engineering and Science
Electronic devices and sensors. Novel instrumentation methods, characterization and modeling of electronic defects in materials and devices. Sensing and light emitting polymers. Quantum computing and devices using self organized monolayers. Intelligent manufacturing using imbedded sensors

Philip Taylor, Ph.D. (Cambridge University, England)
Perkins Professor of Physics
Phase transitions and equations of state for crystalline polymers; piezoelectricity and pyroelectricity

Adjunct Faculty

Giancarlo Capaccio, Ph.D. (University of Rome)
Adjunct Professor
Structural and morphological characterization of polyolefins; structural origins and control of the mechanical and thermal properties of polymers

Edward A. Collins, Ph.D. (University of Manitoba, Canada)
Adjunct Professor
Colloid and surface science and rheology; characterization and morphology of polymers

Steven D. Hudson, Ph.D. (University of Massachusetts)
Adjunct Professor
Development of polymeric materials with novel structure and properties; electron microscopy; diffraction; coalescence, aggregation, phase inversion, nanocomposites, liquid crystals, and supramolecular assemblies.

Bachelor of Science in Engineering Degree Major in Polymer Science

Freshman Year — Class-Lab-Credit Hours

Fall

Open elective or Humanities/Social Science [b]	(3-0-3)
CHEM 111 Principles of Chemistry for Engineers	(4-0-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(16-5-17)**

Spring

Humanities/Social Science or open elective [b]	(3-0-3)
ENGR 145 Chemistry of Materials	(4-0-4)
MATH 122 Calculus for Science and Engineering II	(4-0-4)
PHYS 121 General Physics I	(4-0-4)
PHED 102 Physical Education Activities	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

Humanities or Social Science Sequence I	(3-0-3)
CHEM 223 Organic Chemistry I	(3-0-3)
EMAC 270 Introduction to Polymer Science [c]	(3-0-3)
MATH 223 Calculus for Science and Engineering III	(3-0-3)
PHYS 122 General Physics II	(4-0-4)
Total	**(16-0-16)**

Spring

Humanities or Social Science Sequence II	(3-0-3)
CHEM 224 Organic Chemistry II	(3-0-3)
EMAC 276 Polymer Properties and Design	(3-0-3)
MATH 224 Elementary Differential Equations	(3-0-3)
or	
MATH 234 Introduction to Dynamic Systems	(3-0-3)
ENGR 225 Thermodynamics, Fluid Mechanics, and Heat and Mass Transfer	(4-0-4)
Total	**(16-0-16)**

Junior Year — Class-Lab-Credit Hours

Fall

Humanities or Social Science Sequence III	(3-0-3)
Natural Science elective [a]	(3-0-3)
CHEM 290 Chemistry Laboratory Methods for Engineers *	(1-5-3)
EMAC 351 Physical Chemistry for Engineers I [c]	(3-0-3)
ENGR 200 Statics and Strength of Materials	(3-0-3)
Total	**(13-5-15)**

* CHEM 321 may be substituted

Spring

EMAC 352 Physical Chemistry for Engineers II	(3-0-3)
EMAC 272 Polymer Analysis Laboratory	(2-4-3)
EMAC 376 Polymer Engineering	(3-0-3)
ENGL 398N Professional Communication	(3-0-3)
Technical elective [e]	(3-0-3)
Total	**(14-4-15)**

Senior Year

Fall

Humanities or Social Science elective	(3-0-3)
ENGR 210 Introduction to Circuits & Instrumentation	(4-0-4)
EMAC 377 Polymer Processing	(3-0-3)
EMAC 398 Polymer Science & Engineering Project [c, d]	(0-9-3)
Technical elective [e]	(3-0-3)
Total	**(13-9-16)**

Spring

Humanities or Social Science elective	(3-0-3)
EMAC 378 Polymer Production and Technology	(3-0-3)
EMAC 372 Polymer Processing Laboratory	(2-4-3)
Technical elective [e]	(3-0-3)
Technical elective [e]	(3-0-3)
Open elective	(3-0-3)
Total	**(17-4-18)**

Hours required for graduation: 128

a. Approved Natural Science electives: PHYS 221 or 223, General Physics III; BIOL 210, Molecular Cell Biology; BIOL 205, Chemical Biology; STAT 312, Basic Statistics for Engr. & Sci.; PHYS 349, Methods of Mathematical Physics; BIOC 307, General Biochemistry.
b. One of these courses must be a humanities/social science course.
c. Engineering Core Courses.
d. Preparation for the polymer science project should commence in the previous semester.
e. Technical sequence must be approved by department advisor.

Frank N. Kelley, Ph.D. (University of Akron)
Adjunct Professor (University of Akron)
Polymer structure-property relationships; rheology; material characterization; fracture; life prediction
Scott E. Rickert, Ph.D. (Case Western Reserve University)
Adjunct Professor
Conducting polymers; microdevices; polymer electrodes; polymer adsorption
John C. Weaver, Ph.D. (University of Cincinnati)
Internal Adjunct Professor
Coatings science and technology
James L. White, Ph.D. (University of Delaware)
Adjunct Professor (University of Akron)
Polymer melt-solution rheology and fluid mechanics; elastomers; polymer liquid crystals and aromatic polyamides
Theodore Williams, Ph.D. (University of Connecticut)
Adjunct Professor (College of Wooster)
Bioanalytical chemistry with special interest in human eye tissues and teeth

Undergraduate Program

In 1970, the department introduced a program leading to the Bachelor of Science in Engineering degree with a major in polymer science, which is designed to prepare the student both for employment in polymer-based industry and for graduate education in polymer science. The Case School of Engineering is proud that this was the first such undergraduate program in the country to receive accreditation from the Engineering Council for Professional Development. The curriculum combines courses dealing with all aspects of polymer science and engineering with basic courses in chemistry, physics, mathematics, and biology, depending on the needs and interests of the student. The student chooses a sequence of technical electives, in consultation with a faculty advisor, allowing a degree of specialization in one particular area of interest, e.g., polymer materials, chemical engineering, biopolymers, biochemistry, or physics. In addition to required formal laboratory courses, students are encouraged to participate in the research activities of the department, both through part-time employment as student laboratory technicians and through the senior project requirement-a one-or two-semester project that involves the planning and performance of a research project.

Polymer science undergraduates are also strongly encouraged to seek summer employment in industrial laboratories during at least one of their three years with the department. In addition to the general undergraduate curriculum in macromolecular science, the department offers three specialized programs which lead to the B.S. with a macromolecular science major. The cooperative program contains all the course work required for full-time resident students plus one or two six-month cooperative sessions in polymer-based industry. The company is selected by the student in consultation with his or her advisor, depending on the available opportunities. The dual-degree program allows students to work simultaneously on two baccalaureate level degrees within the University. It generally takes five years to complete the course requirements for each department for the degree. The B.S./M.S. program leads to the simultaneous completion of requirements for both the master's and bachelor's degrees. Students with a minimum GPA of 3.0 may apply for admission to this program in their junior year.

Mission Statement

To educate students who will excel and lead in the development of polymeric materials and the application of structure-property relationships. The department seeks to prepare students for either professional employment or advanced education, primarily in this or related science or engineering disciplines, but also in professional schools of business, law or medicine. Undergraduate students are offered opportunities for significant research experience, capitalizing on the strength of our graduate program.

Specifically, the undergraduate program provides the following educational objectives:

Mastery of Fundamentals

1. Ability to apply knowledge of mathematics, science, and engineering, in general, and synthetic chemistry, polymer processing and structure property relationships of polymeric materials, in particular.
2. Ability to design and conduct experiments (safely and efficiently), to analyze and interpret data, and to critically evaluate hypotheses, by providing experience with synthetic chemistry, polymer processing and measurement techniques.
3. Practical ability to use analytical techniques, computers, information databases and tools for electronic communication.

Creativity

4. Ability to identify, formulate and solve engineering problems that involve materials selection or improvement.
5. Ability to design a polymeric material or process to meet desired needs.

Societal Awareness

6. Broad education necessary to understand the environmental and economic impact of engineering solutions in a global and societal context.
7. Knowledge of contemporary economic, political, scientific and industrial issues.

Leadership Skills

8. Proficiency in oral and written communication, being able to describe clearly either the results of a project or the need for a proposed one.
9. Awareness of the multidisciplinary nature of macromolecular science and engineering, including, synthetic chemistry, polymer fabrication and processing, biomaterials and biomimicry, and mechanical, fluid, electrical, optical and sensing properties of polymers.
10. Ability to function in teams.

Professionalism

11. Exposure to the issues of professional and ethical responsibility.
12. Recognition of the need for, and an ability to engage in lifelong learning.

Graduate Program

Courses leading to the Master of Science and Doctor of Philosophy degrees in macromolecular science are offered within the Case School of Engineering. They are designed to increase the student's knowledge of macromolecular science and of his own basic area of scientific interest, with application to specific polymer research problems. Research programs derive particular benefit from close cooperation with graduate programs in chemistry, physics, materials science, chemical engineering, biological sciences, and other engineering areas. The interdisciplinary academic structure allows the faculty to fit the individual program to the student's background and career plans. Basic and advanced courses are offered in polymer synthesis, physical chemistry, physics, biopolymers, and applied polymer science and engineering. A laboratory course in polymer characterization instructs students in the use of modern experimental techniques and equipment. Graduate students are also encouraged to take advanced course work in polymer solid state physics, physical chemistry, synthesis, rheology, and polymer processing. The department also offers, in conjunction with the School of Medicine, a six- to seven-year M.D./Ph.D. program for students interested in the application of polymers and plastics to medicine, as well as for students interested in a molecular structural basis of medicine, particularly related to connective tissues, biomechanics, aging, pharmaceuticals, and blood behavior. Initiated in 1977, it is the only program of its kind in the nation.

Facilities

The Kent Hale Smith Science and Engineering Building houses the Department of Macromolecular Science. The building was built in 1993, and specifically designed to meet the specific needs of polymer research. The facility consists of five floors, plus a basement. The laboratories for chemical synthesis are located principally on the top floor, the molecular and materials characterization laboratories on the middle floors, and the major engineering equipment on the ground floor, while the electron microscopes are located in the basement. Electronic classrooms are being installed on the ground floor. Laboratories and instrumentation include the X-ray Laboratory, with diffraction and fluorescence equipment; the Electron Microscopy Laboratory, with transmission and scanning electron microscopes; the Molecular Spectroscopy Laboratory, with a complete range of spectroscopic equipment including FTIR, high resolution solution and solid-state NMR (including imaging, computerized laser Raman spectrophotometers, and a high speed/high sensitivity polymer analysis system; and the Biological Materials Laboratory, with facilities for characterization of certain aspects of structure, size, and shape of biological materials. The Polymer Microdevice Laboratory operates in an ultra-clean environment and uses the Langmuir-Blodgett technique of film deposition. There are also facilities for polymer characterization, optical microscopy, scanning calorimetry, and for testing and evaluating the mechanical properties of materials. The C. Richard Newpher polymer composite processing laboratory includes a high temperature Rheometrics RMS-800 dynamic mechanical spectrometer, a Bomem DA-3 FTIR with FT-Raman capabilities, a pultrusion machine, several RIM machines, a compression molding machine, a Brabender plasticorder, a high speed Instron testing machine, and a vibrating sample magnetometer. The Charles E. Reed '34 Laboratory is concerned with the mechanical analysis of polymeric materials. The major testing is done by Instron Universal testing instruments including an Instron model 1123 with numerous accessories such as an environmental chamber for high or low temperature experiments. The laboratory also has an Atomic Force Microscope which probes the morphological and mechanical properties of materials at the nanoscale. The EPIC Molecular Modeling Center contains high-end and low-end Silicon Graphics Computers and various software packages for molecular modeling of polymers.

Research

The research activities of the department span the entire scope of macromolecular science and polymer technology.

Synthesis

New types of macromolecules are being made in the department's synthesis laboratories. The emphasis is on creating polymers with novel functional properties such as photoconductivity, selective permeation, and biocompatibility.

Physical Characterization

This is the broad area of polymer analysis, which seeks to relate the structure of the polymer at the molecular level to the bulk properties that determine its actual or potential applications. This includes characterization of polymers by infrared, Raman, and NMR spectroscopy, thermal and rheological analysis, determination of structure and morphology by x-ray diffraction, electron microscopy, and atomic force microscopy, and investigation of molecular weights and conformation by light scattering.

Mechanical Behavior and Analysis

Polymeric materials are known for their unusual mechanical capabilities, usually exploited as components of structural systems. Analysis includes the study of viscoelastic behavior, yielding and fracture phenomena and a variety of novel irreversible deformation processes.

Processing

A major concern of industry is the efficient and large scale production of polymer materials for commercial applications. Research in this area is focusing on reactive processing, multi-layer processing and polymer mixing, i.e., compounding and blends.

Materials Development and Design

Often, newly conceived products require the development of polymeric materials with certain specific properties or design characteristics. Materials can be tailor-made by designing synthesis and processing conditions to yield the best performance under specified conditions. Examples might be the design of permselective membranes for use in kidney dialysis, polymers that are stable at high temperatures for fire-retardant construction materials, high temperature polymer electrolytes for use in advanced fuel cells, and high-strength nonreactive polymers for use as biological implants.

Biopolymers

Living systems are composed primarily of macromolecules, and research is in progress on several projects of medical relevance. The department has a long-standing interest in the hierarchical structure and properties of the components of connective tissues(e.g., skin, cartilage, and bone). The department is also engaged in the development of new biocompatible polymers for application as biomaterials.

Macromolecular Science and Engineering (EMAC)

Undergraduate Courses

EMAC C100. Co-op Seminar I for Macromolecular Science and Engineering (1)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 001.

EMAC C200. Co-op Seminar II for Macromolecular Science and Engineering (2)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 002 and EMAC C100.

EMAC 270. Introduction to Polymer Science and Engineering (3)
Science and engineering of large molecules. Correlation of molecular structure and properties of polymers in solution and in bulk. Control of significant structural variables in polymer synthesis. Analysis of physical methods for characterization of molecular weight, morphology, rheology, and mechanical behavior. Prereq: ENGR 145.

EMAC 276. Polymer Properties and Design (3)
Engineering properties of polymers and their evaluation in terms of selection and design procedures. Relation of properties to the chemical and physical structures of polymers and application conditions. Prereq: ENGR 145.

EMAC 303. Structure of Biological Materials (3)
This course on the structure of biological materials is designed to provide students with: (i) a fundamental understanding of the structure of biologic materials including globular and structural proteins, connective tissue and bone, from the molecular to the microscopic levels of structure (approx. 65% of course); (ii) an introduction to the basic principles and applications of instruments for imaging, identification and measurement of biologic materials (approx. 25% of course) and (iii) an introduction to methods of bioengineering, biological materials, and novel biomaterials (approx. 10% of course). Prereq: EBME 201 and EBME 202. Cross-listed as EBME 303.

EMAC 351. Physical Chemistry for Engineering I (3)
Principles of physical chemistry and their application to systems involving physical and chemical transformations. Gases, liquids, solids and solutions; first, second and third laws of thermodynamics; thermochemistry; physical and chemical equilibria. Prereq: ENGR 145 or MATH 223 or PHYS 122 or consent of instructor.

EMAC 352. Physical Chemistry for Engineering II (3)
Continuation of EMAC 351. Phase rule, electrochemistry, kinetics of chemical reactions, surface phenomena, contact catalysis, and colloids. Prereq: EMAC 351.

EMAC 355. Polymer Analysis Laboratory (3)
Experimental techniques in polymer synthesis and characterization. Synthesis by a variety of polymerization mechanisms. Quantitative investigation of polymer structure by spectroscopy, diffraction and microscopy. Molecular weight determination. Physical properties. Prereq: EMAC 270 or MATH 224 or MATH 234.

EMAC 372. Polymer Processing and Testing Laboratory (3)
Basic techniques for the rheological characterization of thermoplastic and thermoset resins; "hands-on" experience with the equipment used in polymer processing methods such as extrusion, injection molding, compression molding; techniques for mechanical characterization and basic principles of statistical quality control. Prereq: EMAC 377.

EMAC 375. Introduction to Fundamentals and Practice of Rheology (3)
Elementary coverage of principles and concepts pertaining to a basic description of rheological (flow) behavior of polymeric and colloidal systems. Rheometry and rheological measurements of viscoelastic fluids. Modern theories of polymer dynamics and suspension rheology. Molecular theories of polymer processing behavior. Prereq: ENGR 225.

EMAC 376. Polymer Engineering (3)
Mechanical properties of polymer materials as related to polymer structure and composition. Visco-elastic behavior, yielding and fracture behavior including irreversible deformation processes. Prereq: EMAC 276 and ENGR 200.

EMAC 377. Polymer Processing (4)
Application of the principles of fluid mechanics, heat transfer and mass transfer to problems in polymer processing; elementary steps in polymer processing (handling of particulate solids, melting, pressurization and pumping, mixing); principles and procedures for extrusion, injection molding, reaction injection molding, secondary shaping. Prereq: ENGR 225.

EMAC 378. Polymer Production and Technology (3)
Engineering operations for industrial polymerization procedures. Finishing and fabrication of polymers. Production and technology of plastics, elastomers, fibers, and coatings. Prereq: EMAC 276.

EMAC 396. Special Topics (1-18)
(Credit as arranged.)

EMAC 397. Special Topics (1-18)
(Credit as arranged.)

EMAC 398. Polymer Science and Engineering Project I (1-9)
(Senior project.) Research under the guidance of staff, culminating in thesis.

EMAC 399. Polymer Science and Engineering Project II (1-9)
(Senior project.) Research under the guidance of staff, culminating in thesis.

Graduate Courses

EMAC 400T. Graduate Teaching I (0)
This course will engage the Ph.D. students in teaching experiences that will include non-contact (such as preparation and grading of homeworks and tests) and direct contact (leading recitations and monitoring laboratory works, lectures and office hours) activities. The teaching experience will be conducted under the supervision of the faculty. All Ph.D. students will be expected to perform direct contact teaching during the course sequence. The proposed teaching experiences for EMAC Ph.D. students are outlined below in association with undergraduate classes. The individual assignments will depend on the specialization of the students. The activities include grading, recitation, lab supervision and guest lecturing. Prereq: Ph.D. student in Macromolecular Science.

EMAC 470. Macromolecular Synthesis (3)
Organic chemistry of macromolecules; mechanism of polyreactions; preparation of addition, condensation, and biopolymers; the chemical reactions of polymers. Prereq: EMAC 270. Cross-listed as CHEM 470.

EMAC 471. Polymers in Medicine (3)
Distribution of plastic implants in the body, including history and statistics; chemical and physical characteristics of biomedical polymers, including general implant requirements, reactions of the host to implants, reactions of implants to physiological conditions, physiological and biomechanical basis for soft-tissue implants; plastic materials used in medicine and surgery; frontiers in biomedical polymers (current topics directed to the design and development of new biomedical polymers). Prereq: Consent of instructor. Cross-listed as EBME 406.

EMAC 472. Physical Chemistry of Macromolecules (3)
Major areas of physical chemistry of macromolecules; theories and experimental methods of polymer solutions, physical methods for determination of chemical structure, configuration. Prereq: EMAC 270.

EMAC 473. Biopolymers (3)
Application of physical techniques (X-ray, electron microscopy, infrared and Raman spectroscopy, circular dichroism, etc.) to the characterization of biopolymers, including polypeptides, polysaccharides, and polynucleotides. Prereq: EMAC 270.

EMAC 474. Macromolecular Physics (3)
Physics of amorphous and crystalline polymers. Equilibrium elastic properties of rubbery materials. Viscoelasticity. Liquid-glass and glass-glass transitions. Macromolecular phase transition, including crystallization and phase separation. Prereq: EMAC 270.

EMAC 475. Introduction to Fundamentals and Practice of Rheology (3)
Elementary coverage of principles and concepts pertaining to a basic description of rheological (flow) behavior of polymeric and colloidal systems. Rheometry and rheological measurements of viscoelastic fluids. Modern theories of polymer dynamics and suspension rheology. Molecular theories of polymer processing behavior. Prereq: ENGR 225.

EMAC 476. Polymer Engineering (3)
Mechanical properties of polymer materials as related to polymer structure and composition. Visco-elastic behavior, yielding and fracture behavior including irreversible deformation processes. A term paper is required. Prereq: EMAC 276 and ECIV 110.

EMAC 477. Polymer Processing (3)
Rheological, molecular, structural, engineering, and compounding factors affecting processibility and properties of polymers; principles and procedures for mixing, extrusion, melting, calendering, injection molding, and other primary processing methods. Pertinent mechanisms and theories; the application of theory to practice. Prereq: EMAC 376.

EMAC 479. X-ray Crystallography (3)
Scattering of X-rays by crystalline and semi-crystalline solids, including polymers. Techniques of structure analysis.

EMAC 480. Polymer Morphology (3)
The morphology of semicrystalline and amorphous polymers, fibers, blends, liquid-crystalline polymers, and composites; and the physical and

chemical mechanisms that control morphology. Practical knowledge of optical and electron microscopy: lab experiments and a project are included. Prereq: EMAC 474.

EMAC 482. Fundamentals of Adhesives, Sealants, and Coatings (3)
Film formation, application methods, and related fabrication factors and procedures. Relevant adhesion theories and practices, aspect of rheological treatments, and factors which affect these applications. Properties of constituent polymer materials, pigments, solvents, and other additives.

EMAC 500T. Graduate Teaching II (0)
This course will engage the Ph.D. students in teaching experiences that will include non-contact (such as preparation and grading of homework and tests) and direct contact (leading recitations and monitoring laboratory works, lectures and office hours) activities. The teaching experience will be conducted under the supervision of the faculty. All Ph.D. students will be expected to perform direct contact teaching during the course sequence. The proposed teaching experiences for EMAC Ph.D. students are outlined below in association with graduate classes. The individual assignments will depend on the specialization of the students. The activities include grading, recitation, lab supervision and guest lecturing. Prereq: Ph.D. student in Macromolecular Science.

EMAC 570. Functional and Reactive Polymers: Synthesis and Properties (3)
The design, synthesis, and properties of a number of new and growing areas of polymer science and chemistry. Topics will include (1) Functional polymers e.g., conducting, light emitting, and liquid crystalline polymers. (2) Reactions with polymers e.g., solid-phase synthesis (peptide and DNA synthesis and combinatorial chemistry), polymers reagents. (3) Supramolecular chemistry in polymeric systems e.g., molecular imprinting, main chain supramolecular polymers, effect on miscibility, etc. (4) Synthesis and properties of different polymeric architectures: dendrimers, ladder polymers, polyrotaxanes, etc. and (5) New developments in polymer catalysts.

EMAC 600T. Graduate Teaching III (0)
This course will engage the Ph.D. students in teaching experiences that will include non-contact and direct contact activities. The teaching experience will be conducted under the supervision of the faculty. The proposed teaching experiences for EMAC Ph.D. student in this course involve instruction in the operation of major instrumentation and equipment used in the daily research activities. The individual assignments will depend on the specialization of the students. Prereq: Ph.D. student in Macromolecular Science.

EMAC 601. Independent Study (1-18)
(Credit as arranged.)

EMAC 651. Thesis M.S. (1-18)
(Credit as arranged.)

EMAC 671. Topics in Macromolecular Science (1-36)

EMAC 673. Selected Topics in Polymer Engineering (2-3)
Timely issues in polymer engineering are presented at the advanced graduate level. Content varies, but may include: mechanisms of irreversible deformation: failure, fatigue and fracture of polymers and their composites; processing structure-property relationships; and hierarchical design of polymeric systems. Prereq: EMAC 376 or EMAC 476.

EMAC 674. Selected Topics (3)

EMAC 677. Colloquium in Macromolecular Science (0)
Lectures by invited speakers on subjects of current interest in polymer science.

EMAC 678. Characterization of Macromolecules (3)
Laboratory experience through synthesis and characterization of polymers. Methods include light scattering, viscosity, infrared, and NMR spectroscopy. Solid samples characterized by x-ray diffraction, electron and optical microscopy, thermal analysis, and physical properties. Prereq: EMAC 470 and EMAC 472.

EMAC 690. Special Topics in Macromolecular Science (1-18)

EMAC 701. Dissertation Ph.D. (1-18)
(Credit as arranged.)

EMAC 702. Appointed Dissertation Fellow (9)

Department of Materials Science and Engineering

500 White Building (7204)
Phone 216-368-4230; Fax 216-368-3209
Gary Michal, Chair
e-mail gmm3@po.cwru.edu
http://case.cwru.edu/departments/

Materials science and engineering is a discipline that extends from the basic science of materials structure and properties to the design and evaluation of materials in engineering systems. Most engineers—mechanical, civil, chemical, and electrical—work with materials on the job, and many become well acquainted with the properties of the materials they use most often. The role of a materials engineer is to understand why materials behave as they do under various conditions; to recognize the limits of performance that particular materials can attain; and to know what can be done during the manufacture of materials to meet the demands of a given application.

The Department of Materials Science and Engineering of the Case School of Engineering offers programs leading to the Bachelor of Science in Engineering, Master of Science, and Doctor of Philosophy degrees. The department conducts academic and research activities with metals, ceramics, composites, and electronic materials. Increasingly, the demands for new materials, and for improved materials in existing applications, transcend the traditional categories. The technological challenges that materials engineers face will continue to demand a breadth of knowledge across the spectrum of engineering materials.

Materials science draws on chemistry in its concern for bonding, synthesis, and composition of engineering materials and their chemical interactions with the environment. Physics provides a basis for understanding the mechanical, thermal, and electrical properties of materials, as well as the tools needed to ascertain the structure and properties of materials. Mathematics is used throughout materials manufacture and analysis. Ultimately, however, materials is an engineering discipline, bringing basic science tools to bear on the technological challenges related to materials products and their manufacture.

Faculty

Gary M. Michal, Ph.D. (Stanford University)
LTV Steel Professor and Chair
Physical metallurgy; rapid solidification technology; application of rapid annealing to nonequilibrium precipitation reactions; transmission electron microscopy; surface science; composite materials; interfacial phenomena

James D. Cawley, Ph.D. (Case Western Reserve University)
Great Lakes Professor of Ceramic Processing and Associate Dean of Engineering
Powder processing of ceramics; aggregation phenomena; oxidation, diffusion, and solid state reactions; silicate and active metal brazing of ceramics; ceramic matrix composites

Mark R. DeGuire, Ph.D. (Massachusetts Institute of Technology)
Associate Professor
Low-temperature synthesis of ceramic thin films. Synthesis and properties of electrical ceramics in bulk and thin-film form, including dielectrics, ferroelectrics, semiconductors, and ferrites. High-temperature phase equilibria. Defect chemistry

Frank Ernst, Ph.D. (University of Göttingen)
Professor
Microstructure and microcharacterization of materials; defects in crystalline materials; interface and stress-related phenomena; semiconductor heterostructures, plated metallization layers; photovoltaic materials; surface hardening of alloys, quantitative methods of transmission electron microscopy.

Arthur H. Heuer, Ph.D., D.Sc. (University of Leeds, England)
University Professor and Kyocera Professor of Ceramics
Transformation toughening and plastic deformation of ceramics; phase transformations in ceramics; biological ceramics; interphase interfaces in advanced structural composites; high resolution and analytical electron microscopy Matterials Science of MEMS, thermal barrier coatings, solid oxide fuel cells

Harold Kahn (Massachusetts Institute of Technology)
Research Associate Professor
Microelectromechanical systems involving design, fabrication, fatigue and fracture mechanics testing of surface-micromachined polysilicon and SiC devices and bulk-micromachined microfluidic devices using TiNi shape memory actuators.

Peter Lagerlof, Ph.D. (Case Western Reserve University)
Associate Professor
Electron microscopy; high temperature mechanical properties of single crystal and polycrystal oxide and nitride ceramics; oxygen diffusion in oxide ceramics

Bachelor of Science in Engineering Degree Major in Materials Science & Engineering

Freshman Year — Class/Lab/Credit Hours

Fall

CHEM 111 Principles of Chemistry for Engineers	(4-0-4)
ENGR 131 Elementary Computer Programming	(3-0-3)
ENGL 150 Expository Writing	(3-0-3)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
PHED 1xx Physical Education Activities	(0-3-0)
Open Elective or Humanities/Social Science Elective [b,g]	(3-0-3)
Total	**(17-3-17)**

Spring

ENGR 145 Chemistry of Materials	(4-0-4)
MATH 122 Calculus for Science and Engineering II	(4-0-4)
PHYS 121 General Physics I - Mechanics [a]	(3-1-4)
PHED 1xx Physical Education Activities	(0-3-0)
Humanities/Social Science or Open elective [b, g]	(3-0-3)
Total	**(14-4-15)**

Sophomore Year

Fall

CHEM 301 Introduction to Physical Chemistry [c]	(3-0-3)
EMSE 102 Materials Science Seminar	(1-0-1)
EMSE 201 Introduction to Materials Science & Engr.	(3-0-3)
MATH 223 Calculus for Science and Engineering III	(3-0-3)
PHYS 122 General Physics II - Electricity & Magnetism	(3-1-4)
Humanities/Social Science Elective [g]	(3-0-3)
Total	**(16-1-17)**

Spring

ECES 251 Numerical Methods [d]	(3-0-3)
EMSE 202 Phase Diagrams & Phase Transformations	(3-0-3)
EMSE 270 Materials Laboratory I	(0-3-2)
MATH 224 Elementary Differential Equations [e]	(3-0-3)
ENGR 200 Statics and Strength of Materials	(3-0-3)
Humanities/Social Science Sequence I	(3-0-3)
Total	**(15-3-17)**

Junior Year — Class/Lab/Credit Hours

Fall

EMSE 280 Materials Laboratory II	(0-3-2)
ENGR 210 Introduction to Circuits and Instrumentation	(3-2-4)
EMSE 203 Applied Thermodynamics	(3-0-3)
EMSE 314 Electronic, Magnetic, and Optical Properties of Materials	(3-0-3)
Humanities/Social Science Sequence II	(3-0-3)
Total	**(12-5-15)**

Spring

EMSE 290 Materials Laboratory III	(0-3-2)
ENGL 398N Professional Communication [f]	(3-0-3)
EMSE 303 Mechanical Behavior of Materials	(3-0-3)
ENGR 225 Thermodynamics, Fluid Mechanics & Heat & Mass Transport	(4-0-4)
Humanities/Social Science Sequence III	(3-0-3)
Technical Elective	(3-0-3)
Total	**(16-3-18)**

Senior Year

Fall

EMSE 301 Fundamentals of Materials Processing	(3-0-3)
EMSE 302 Fundamentals of Materials Processing Lab.	(0-3-1)
EMSE 310 Applications of Diffraction Principles	(0-2-1)
EMSE 312 Diffraction Principles	(3-0-3)
EMSE 398 Senior Project in Materials I	(0-2-1)
Humanities/Social Science Elective [g]	(3-0-3)
Technical elective	(3-0-3)
Total	**(12-7-15)**

Spring

EMSE 313 Engineering Applications of Materials	(3-0-3)
EMSE 399 Senior Project in Materials II	(0-4-2)
Technical Elective	(3-0-3)
Open elective	(3-0-3)
Open elective	(3-0-3)
Total	**(12-4-14)**

Hours required for graduation: 128

a. Selected students may be invited to take PHYS 123-124; General Physics I-II Honors, in place of PHYS 121-122.
b. One of these must be in the humanities or social sciences.
c. Satisfied the Math, Natural Sciences, or Statistics requirement of the Engineering Core.
d. Or EMAE 250 or PHYS 250.
e. Or MATH 234.
f. Satisfied the Professional Communications requirement of the Engineering Core.
g. The Engineering Core requires that if the Humanities/Social Sciences sequence is in Social Science, then 2 of the 3 Humanities/social Sciences electives must be in Humanities; if the sequence is in Humanities, then 2 of the 3 electives must be in Social Science.

John J. Lewandowski, Ph.D. (Carnegie-Mellon University)
Leonard Case Jr. Professor and Director -Mechanical Characterization Facility
Mechanical behavior of materials; fracture and fatigue; micromechanisms of deformation and fracture; composite materials; bulk metallic glasses and composites; refractory metals; toughening of brittle materials; high-pressure deformation and fracture studies; hydrostatic extrusion; deformation processing

David H. Matthiesen, Ph.D. (Massachusetts Institute of Technology)
Associate Professor
Crystal growth; electronic materials; materials processing in microgravity; effect of growth conditions on the microstructures and electrical properties of semiconductors; fluid dynamics and heat, mass, and momentum transport

Joe H. Payer, Ph.D. (Ohio State University)
Professor
Electrochemistry and corrosion; reliability and life prediction; hydrogen storage, fuel cells, corrosion monitoring and sensors; polymer/metal adhesion

P. Pirouz, Ph.D. (Imperial College of Science and Technology, England)
Professor
Defects in semiconductors; heteroepitaxial growth of electronic materials; diffraction theory; transmission electron microscopy and its applications in materials science; fiber-reinforced composites; synthetic growth of diamond

David Schwam, Ph.D. (The Technion University)
Research Associate Professor
Gating of advanced aluminum and magnesium alloys, development of die and permanent mold materials, thermal fatigue testing, recycling.

James W. Wagner, Ph.D. (The Johns Hopkins University)
Professor
Provost and University Vice President
Coherent optical metrology for nondestructive characterization of materials properties, holographic, interferometric, laser-ultrasonic and related methods, measurement systems, electro-optics, biomedical implants

Gerhard E. Welsch, Ph.D. (Case Western Reserve University)
Professor
Metals and oxides; high temperature properties, electrical and mechanical properties. Materials for energy storage; metal sponges; metal-cell composites. Design and synthesis of structure of materials in the nanometer to mm range. Titanium, tantalum, tungsten, rhenium, iron, nickel alloys

Emeritus Faculty

John Wallace (Massachusetts Institute of Technology)
Professor
Metallurgical processing, casting processes, effect of processing and material properties, die steels

Approved Technical Electives

The following courses are approved technical electives in Materials Science and Engineering. A student is encouraged to discuss with their class advisor a sequence of technical elective courses, which takes into account the biannual nature of some offerings. Students may request approval of other elective courses by submitting a written petition justifying their choices to the department's Undergraduate Studies Committee.

Course Number	Course Title	Fall	Spring	Annual	Bi-Annual
ECIV 210	Strength of Materials	X		X	
ECIV 410	Advanced Strength of Materials	X		X	
ECIV 420	Finite Element Structural Analysis	X		X	
EEAP 245	Circuits, Signals and Systems I		X	X	
EEAP 246	Circuits, Signals and Systems II	X		X	
EEAP 309	Electromagnetic Fields I	X		X	
EEAP 321	Semiconductor Electronic Devices		X	X	
EMAC 270	Introduction to Polymer Science	X		X	
EMSE 307	Foundry Metallurgy		X	X	
EMSE 316	Applications of Ceramic Materials	X			X
EMSE 360	Transport Phenomena		X	X	
EMSE 401	Transformations in Materials	X			X
EMSE 403	Modern Ceramic Processing	X			X
EMSE 404	Diffusion Processes in Solids and Liquids	X			X
EMSE 405	Dielectric, Optical, & Magnetic Properties of Materials	X			X
EMSE 407	Solidification of Materials		X		X
EMSE 409	Deformation Processing of Metals		X		X
EMSE 410	Numerical Modeling of Materials Forming Processes	X		X	
EMSE 411	Environmental Effects on Materials Behavior		X	X	
EMSE 417	Properties of Materials at High Temperatures		X		X
EMSE 418	Oxidation of Materials		X		X
EMSE 419	Phase Equilibria & Microstructures of Materials	X			X
EMSE 420	Powder Processing				
EMSE 421	Fracture of Materials	X		X	
EMSE 426	Semiconductor Thin Film Science & Technology		X		X
EMSE 427	Dislocations in Solids		X		X
EMSE 429	Crystallography & Crystal Chemistry		X		X
PHYS 331	Introduction to Quantum Mechanics 1	X		X	
PHYS 315	Introduction to Solid State Physics	X		X	
STAT 312	Statistics for Engineering and Science	X	X	X	
or STAT 313	Statistics for Experimenters	X	X	X	

Secondary Faculty

John Angus, Ph.D. (University of Michigan)
Professor of Chemical Engineering
Roberto Ballarini, Ph.D. (Northwestern University)
Professor of Civil Engineering
Russell Wang, D.D.S. (University of Toronto)
Associate Professor of Dentistry
Adjunct Facutly
Arnon Chait
Professor
NASA Glenn Research, Brookpark, Ohio
Marc Constantino
Professor
Lawrence Livermore Laboratory, Livermore, CA
George Fischer
Professor
IVAC Technologies, Cleveland
Peter M. Hazzledine
Professor
UES, Inc., Dayton, Ohio
N. J. Henry Holroyd
Professor
Luxfer, USA, Riverside, California
Warren H. Hunt, Jr.
Professor
Aluminum Consultants Group, Inc., Murrysville, PA
Jennie S. Hwang
Professor
H-Technologies Group, Cleveland
Terence Mitchell
Professor
Los Alamos National Laboratory, Los Alamos, NM
Gary Ruff
Professor
Intermet Corp., Troy, Michigan
Rolf Steinbrech
Professor
University of Dortmund, Germany
Urs Häfeli
Associate Professor
The Cleveland Clinic Foundation, Cleveland, Ohio
Wendell S. Williams (Retired)
Professor

Undergraduate Programs

The goal of the undergraduate program is to prepare our graduates for challenging and productive careers related to the science and engineering of materials, especially metals, ceramics, electronic materials, and composites. The primary means of accomplishing this mission is our undergraduate curriculum and associated activities, through their emphasis on

- The interrelationships among the processing, structure, properties, and performance of engineering materials
- The mutual reinforcement of education and professional development throughout one's career.

The undergraduate curriculum leading to the degree of Bachelor of Science in materials science and engineering consists of the "Engineering Core"—basic courses in mathematics, physics, chemistry, and engineering, with electives in social sciences and humanities—plus materials courses, technical electives, and open electives. A total of 128 credit hours is required. Please see the table for the recommended semester-by-semester listing of courses.

The educational objectives of the undergraduate program are as follows

1. Graduates will understand the interrelationships among processing, structure, and properties of a wide range of engineering materials, and how these factors together control the materials performance.
2. Graduates will be able to carry out laboratory experiments, analyze data, and interpret the significance of their results, especially with respect to the processing of engineering materials and characterization of their engineering properties.
3. Graduates will be proficient in the oral, written, and electronic communication of their ideas.
4. Graduates will be proficient in the use of computer technology and computer-based information systems.
5. Graduates will be able to function effectively in groups of peers and independently.
6. Graduates will be informed of the impact of engineering on society and of the professional, ethical, safety, and environmental responsibilities that that entails.
7. Graduates will regard professional development and education as processes that should continue hand-in-hand throughout their academic and professional careers.

The undergraduate experience in Materials Science and Engineering at Case Western Reserve is marked by a high degree of hands-on experience and many opportunities for professional development before graduation. Lab courses, senior projects, and plant tours ensure that every student sees the field first-hand in current research and industrial settings.

In addition, many of our undergraduate students participate in co-operative education, summer jobs, and professional societies that expose them to the larger world of materials science beyond the classroom

Minor in Materials Science and Engineering

In addition to the Bachelor of Science degree program in materials science and engineering, the department also offers a minor in materials science and engineering. This sequence is intended primarily for students majoring in science or engineering, but it is open to any student with a sound background in introductory calculus, chemistry, and physics. This program requires the completion of 5 courses with a minimum of 15 credit hours, of which a maximum of 6 hours can be counted toward the student's major. All students will be required to take EMSE 201 (3) and four of the following courses

- EMSE 202, Phase Diagrams and Phase Transformations (3)
- EMSE 203, Applied Thermodynamics (3)
- EMSE 260, Transport Phenomena (4)
- EMSE 301, Fundamentals of Materials Processing (3)
- EMSE 303, Mechanical Behavior of Materials (3)
- EMSE 307, Foundry Metallurgy (3)
- EMSE 313, Engineering Applications of Materials (3)
- EMSE 314, Electrical, Magnetic, and Optical Properties (3)
- EMSE 316, Applications of Ceramics (3)
- EMSE 317, Diffraction Principles and Applications (4)

Prof. Mark DeGuire (506 White; x-4221) is the academic advisor for this program and will assist students with their course selection.

Cooperative Education in Materials Science and Engineering

The Cooperative Education program at Case Western Reserve began in the Materials Science and Engineering Department and the department's faculty continue to strongly support student participation. Over the past ten years approximately three-quarters of the department's undergraduates have completed at least one cooperative education assignment. Most students complete the recommended two assignments. A wide range of opportunities exist for materials majors including heavy industry, mid-size and small firms, and government and corporate research centers. Many opportunities are local to Northern Ohio, but a wide range of possibilities around the country, and, occasionally, international opportunities arise.

The cooperative education experience is monitored to ensure that students progress in job responsibilities during the course of an assignment. It is common for students to assume positions of responsibility, including employee supervision or decision-making on behalf of the company.

The department offers two academic courses, EMSE C100 and EMSE C200, that may be taken for credit upon return from the first and second experience respectively.

Five-Year Combined B.S./M.S. Program

This program offers outstanding undergraduate students the opportunity to obtain an M.S. degree, with a thesis, in one additional year of study beyond the B.S. degree. (Normally, it takes 2 years beyond the B.S. to earn an M.S. degree.) In this program, an undergraduate student can take up to nine credit hours that simultaneously satisfy undergraduate and graduate requirements. Typically, students in this program start their research leading to the M.S. thesis in the fall semester of the senior year. The department endeavors to support such students through the following summer and academic year at the normal stipend for entering graduate students. The B.S. degree is awarded at the completion of the senior year.

Application for admission to the five year B.S./M.S. program is made after completion of five semesters of course work. Minimum requirements are a 3.2 grade point average and the recommendation of the department. Interested students should contact Professor Cawley.

Graduate Programs

The department offers programs leading to the Master of Science and Doctor of Philosophy degrees with research specialties in metallurgy, ceramics, electronic materials, composite materials, and materials science. A broad range of studies of the theory, properties, and engineering behavior of materials is encompassed in the academic courses and research within the department, with primary areas of specialization in materials processing, mechanical properties, surface and microstructural characterization, environmental effects, and electronic materials.

M.S. Degree Requirements

The M.S. degree in materials science and engineering is awarded through either Plan A (Master's Thesis) or Plan B (Master's Comprehensive). Plan A involves a thesis based on individual research and a final oral thesis defense; this plan is appropriate for full-time graduate students. Plan B involves a major project and a comprehensive oral exam; it is typically pursued by part-time graduate students.

Plan A requires successful completion of 6 courses (18 credit hours) and at least 9 credit hours of M.S. research project (EMSE 651). Plan B requires the successful completion of eight courses (24 credit hours) as well as 3 credit hours of a Special Projects course (EMSE 649). The six courses for Plan A and the 8 courses for Plan B may include a maximum of 2 courses from an engineering or science curriculum outside the department. No more than 2 courses at the 3xx level can be included; all other courses must be at a higher level. Transfer of credit from another university is limited to six credit hours of graduate level courses (with grade B or better) taken in excess of degree requirements at the other university. A Program of Study must be submitted by the end of the first semester for Plan A students, and by the end of 2 courses for Plan B students. A cumulative G.P.A. of 2.75 or higher is required.

Plan A students must prepare a written thesis and successfully defend the thesis in a final oral exam. Plan B students must prepare a written report on his/her special project and satisfactorily pass a comprehensive oral exam. The thesis exam for Plan A and the oral exam for Plan B must be conducted by an examining committee consisting of 3 faculty members of the department.

Ph.D. Degree Requirements

Immediately upon entering the Materials Science and Engineering Department, the Ph.D. candidate must fill out and submit the first part of the "Ph.D. Student Permanent Record" form; register for 2 or 3 classes during the first semester. If only 2 classes are taken, register for EMSE 701 Dissertation Research (3 credit hours) during the first semester. Note that registration for EMSE 701 is not permitted before the form is turned in.

Candidates for a Ph.D. degree in materials science and engineering must meet the following requirements to prove their competency for doctoral study and to be accepted into the doctoral program:

(1) Submit an approved Program of Study form and a Supplementary Information form specifying the Breadth and Basic Science Requirements.

(2) Pass a comprehensive written General Exam within 6 months following their being awarded an M.S. degree (12 months for students with an M.S. degree from a different science or engineering discipline).

(3) Pass a Thesis Proposal Exam (written and oral) during the semester immediately following the successful completion of the written General Exam. These requirements are explained in detail below. At the completion of these requirements, the student must fill out the second part of the Ph.D. Student Permanent Record" form.

Upon successful completion of all requirements and research, the Ph.D. candidate must submit a written dissertation as evidence for his/her ability to conduct independent research at an advanced level. The Ph.D. candidate must pass a final oral exam in defense of the dissertation. The Dissertation Committee must consist of three faculty members of the department and one non-departmental member. The candidate must provide each committee member with a copy of the completed dissertation at least 10 days before the exam, so that the committee members may have an opportunity to read and discuss it in advance.

The student must provide two (2) unbound copies of the final approved version of the thesis for the University, and two (2) bound copies of the thesis, one for the department and one for the student's faculty advisor.

(1) Ph.D. Program of Study (Course Requirements)

A Ph.D. student must take a minimum of 18 credit hours of EMSE 701 and must continue registration each succeeding regular semester (fall and spring) until the dissertation is complete, unless granted a leave of absence. The time limit for the Ph.D. program is 5 years, starting with the first semester of EMSE 701 registration.

The minimum course requirement for a Ph.D. degree is 12 courses (36 credit hours) beyond the B.S. level, out of which at least six courses (18 credit hours) must be taken at Case Western Reserve University. Of these 12 courses, six courses must satisfy the Breadth Requirement and 2 courses must satisfy the Basic Science Requirement for the department as outlined below. In the case of a student entering with an M.S. degree from another discipline, additional courses may be required as decided by the department. A G.P.A. of 3.0 is required for Graduate Assistants.

Breadth Requirement.

A broad knowledge of the field of materials science and engineering includes a minimum level of understanding of the following six areas

a. Mechanical Behavior
b. Structure
c. Physical Properties
d. Processing
e. Thermodynamics and Kinetics
f. Phase Transformations

The Breadth Requirement for the Ph.D. can be fulfilled by taking a total of 6 courses (18 credit hours) ; these 6 courses must include at least one course from areas a, b, c, and d and 2 courses from areas e and f combined. The department maintains a list of approved courses for each of these areas.

Basic Science Requirements.

A minimum depth in basic science of two courses (6 credit hours) is required for a Ph.D. degree. This requirement can be fulfilled by taking 2 courses selected from physics, chemistry, mathematics and/or statistics, and/or certain engineering curricula. The department maintains a current list of approved courses for the Basic Science Requirements.

The Program of Study, a list of the courses the student will take to fulfill the Ph.D. requirements, will be discussed and approved at the time of the Thesis Proposal Exam. This form and the associated Supplementary Information form must be approved by the student's Dissertation Committee (excluding the non-departmental member) and the chair of the department and submitted to the dean of graduate studies within one semester of passing the General Exam.

(2) Ph.D. General Exam

The written General Exam is offered twice a year, typically in January and in June, provided at least three students are registered to take the exam. The Exam is comprehensive and consists of two parts:

1. Thermodynamics and Kinetics; Materials Processing: covering such topics as phase equilibria, phase transformations, diffusion, defect chemistry, synthesis, fabrication, microstructural development, and thermomechancial processing.

2. Structure; Properties, Performance, and Reliability: covering crystallography and symmetry, analytical techniques (diffraction, imaging, and spectroscopy), line defects, surfaces and interfaces, microstructural analysis, mechanical, thermal, chemical (environmental), and electrical, optical, and magnetic properties, individually and in combination.

The emphasis in both parts of this General Exam will be on inorganic materials: metals, ceramics, semiconductors, and composites.

Each part of the exam will last for three hours; the morning session is devoted to part 1 and the afternoon session covers part 2. Each part of the Exam is divided into two sections

Part 1 (morning)

Section 1 Thermodynamics and Kinetics
Section 2 Processing

Part 2 (afternoon)

Section 3 Structure
Section 4 Properties, Performance, and Reliability

The exam is closed book. Each section of the exam will contain a minimum of 4 questions. Students must answer 5 questions from part 1 and 5 questions from part 2, with at least 2 questions being answered from each section.

In order to pass the written General Exam, the criteria are as follows—6 out of ten questions in the exam require a 70% passing grade as well as a 75% average for the whole exam. Students who fail the exam (or the Thesis Proposal Exam described below) may try that exam a second time.

(3) Thesis Proposal Exam

The Thesis Proposal Exam tests the more specific knowledge of the Ph.D. candidate concerning the science underlying the proposed research and to his or her intellectual maturity. It is composed of a written and an oral part, both dealing with the candidate's proposed research project. The written document should be given to each member of the student's Dissertation Advisory Committee (excluding the non-departmental member) during the semester immediately following the successful completion of the General Exam. It should include a literature search, analysis of the research problem, suggested research procedures, and the general results to be expected. The document should be written by the student and not his/her thesis advisor, and will be examined by the student's Dissertation Advisory Committee for this purpose.

The oral part of the Thesis Proposal Exam should last approximately two hours and must be given before the student's Dissertation Advisory Committee within one week of submitting the above written document to the Committee. Both parts of the Thesis Proposal Exam will be graded Pass/Fail.

At the time of this Exam, the student will also have his/her Program of Study examined and approved by the Dissertation Advisory Committee.

Research Areas

Deformation and Fracture

Determination of the relationships between structure and mechanical behavior of traditional and advanced materials—metals, ceramics, intermetallics, composites, and biological materials. State-of-the art facilities are available for testing over a range of strain rates, test temperatures, stress states, and size scales for both monotonic and cyclic conditions.

Materials Processing

Ceramic and metal powder synthesis and processing, computer-aided manufacturing of laminated materials, metals casting, crystal growth, thin film deposition, deformation processing of metals.

Environmental Effects

Corrosion, oxidation, adhesion and wear. Electro-deposited coatings on steel, epoxy/metal adhesion, dis-bonding of coatings, reliability of electronics, corrosion sensors.

Surfaces and Interfaces

Free surfaces, grain boundaries, metal/ceramic, polymer/metal composite interfaces. Major facilities for transmission electron microscopy, scanning electron microcopy, and surface spectroscopies.

Electronic, Magnetic and Optical Materials

Electronic materials—silicon, germanium, gallium arsenide, silicon carbide; gallium nitride; thin film dielectric, optical, and magnetic ceramics; synthesis and characterization of multi-component electromagnetic filters, transparent semiconductors, ceramics, such as materials for sensors, catalysts, and fuel cells.

Facilities

Materials Processing

The department's processing laboratories include facilities which permit materials processing from the liquid state (casting) as well as in the solid state (powder processing). The department has its own foundry that houses mold making capabilities (green and bonded sand, permanent mold, and investment casting), induction melting furnaces of various capabilities for air melting of up to 1500 pounds of steel, electrical resistance furnances for melting and casting up to 800 pounds of aluminum, and 500 pounds of magnesium under protective atmosphere,a dual chamber vacuum induction melting unit with a capacity of up to 30 pounds of superalloys, a 350 ton squeeze casting press, and state-of-the-art thermal fatigue testing and characterization equipment. The Crystal Growth Laboratory has facilities for production of high purity electronic single crystals using a variety of furnaces with the additional capability of solidifying under large magnetic fields. In addition, a CVD and MOCVD reactor has been set up to do research on the growth of SiC and GaN on Si, sapphire, and other substrates. Secondary processing and working can be accomplished using a high-speed hot and cold rolling mill, swaging units, and a state-of-the art hydrostatic extrusion press. The department has heat treatment capabilities including numerous box, tube, and vacuum furnaces. For the processing of powder metals or ceramics the department possesses a 300,000 pound press, a vacuum hot press (with capabilities of up to 7 ksi and 2300 C), a hot isostatic press (2000 C and 30 ksi), a 60 ksi wet base isostatic press, and glove boxes. Sintering can be performed in a variety of controlled atmospheres while a microcomputer-controlled precision dilatometer is available for sintering studies. Several ball mills, shaker mills, and a laboratory model attritor are also available for powder processing.In addition, facilities are available for sol-gel processing, glass melting, diamond machining; a spray dryer is available for powder granulation.

A Deformation Processing Laboratory has recently been commissioned that contains two dual hydraulic MTS presses. The first press is designed to evaluate the stretching and drawing properties of materials in sheet form. Its maximum punch and hold down forces are 150,000 each. Its maximum punch velocity is 11.8 inch/sec. The second press is designed to evaluate the plastic flow behavior of materials in an environment that simulates modern manufacturing processing. The press can deliver up to five consecutive impacts to a material in less than five seconds with a punch velocity as high as 110 inch/sec. The maximum punch force is 110,000 pounds.

A Computational Materials Processing Laboratory has recently been established. The core of the facilities is a Silicon Graphics Origin 2000 which has high speed networking with an array of Octane workstations. A host of software packages are available as tools for the simulation and design of materials processing activities that range from crystal growth to powder consolidation to plastic deformation and also maintains a computer lab expressly for student use, including IBM-compatible and Macintosh computers, laser printers, DEC-net terminals, and a VAX-station 2000 with a large screen high resolution display.

Mechanical Testing Facility

The Mechanical Testing Facility permits the determination of mechanical behavior of materials over loading rates ranging from static to impact, with the capability of testing under a variety of stress states under either monotonic or cyclic conditions. A variety of furnaces and environmental chambers are available to enable testing at temperatures ranging from -196 C to 1800 C. The facility is operated under the direction of a faculty member and under the guidance of a full-time engineer. The facility contains one of the few laboratories in the world for high-pressure deformation and processing, enabling experimentation under a variety of stress states and temperatures. The equipment in this state-of-the-art facility includes:

High Pressure Deformation Apparatus: These units enable tension or compression testing to be conducted under conditions of high hydrostatic pressure. Each apparatus consists of a pressure vessel and diagnostics for measurement of load and strain on deforming specimens, as well as instantaneous pressure in the vessel. Pressures up to 1.0 GPa, loads up to 10kN, and displacements of up to 25 mm are possible. The oil based apparatus is operated at room temperature while a gas (i.e. Ar) based apparatus can be used with an internal furnace.

Hydrostatic Extrusion Apparatus: Hydrostatic extrusion (e.g. pressure-to-air, pressure-to-pressure) can be conducted at temperatures up to 300 C on manually operated equipment interfaced with a computer data acquisition package. Pressures up to 2.0 GPa are possible, with reduction ratios up to 6 to 1, while various diagnostics provide real time monitoring of extrusion pressure and ram displacement.

Advanced Forging Simulation Rig: A multi-actuator..MTS machine based on a 330 kip, four post frame, enables sub-scale forging simulations over industrially relevant strain rates. A 110 kip forging actuator is powered by five nitrogen accumulators enabling loading rates up to 120 inches/sec on large specimens. A 220 kip indexing actuator provides precise deformation sequences for either single, or multiple, deformation sequences. Date acquisition at rates sufficient for analysis is available. Testing with heated dies is possible.

Advanced Metal Forming Rig: A four post frame with separate control of punch actuator speed and blank hold down pressure enables determination of forming limit diagrams. Dynamic control of blank hold down pressure is possible, with maximum punch actuator speeds of 11.8 inches/sec. A variety of die sets are available

The remainder of the equipment in the Mechanical Testing Facility is summarized below:

Servo-hydraulic Machines: Four MTS Model 810 computer-controlled machines with load capacities of 3 kip, 20 kip, 50 kip, and 50 kip, permit tension, compression, and fatigue studies to be conducted under load-, strain-, or stroke control. Fatigue crack growth may be monitored via a dc potential drop technique as well as via KRAK gages applied to the specimen surfaces. Fatigue studies may be conducted at frequencies up to 30 Hz.

Universal Testing Machines: Three INSTRON screw-driven machines, including two INSTRON Model 1125 units permit tension, compression and torsion testing.

Electromechanical Testing Machine: A computer-controlled INSTRON Model 1361 can be operated under load-, strain-, or stroke control. Stroke rates as slow as 1 micrometer/hour are possible.

Fatigue Testing Machines: Three Sonntag fatigue machines and two R. R. Moore rotating-bending fatigue machines are available for producing fatigue-life (S-N) data. The Sonntag machines may be operated at frequencies up to 60 Hz.

Creep Testing Machines: Three constant load frames with temperature capabilities up to 800 C permit creep testing, while recently modified creep frames permit thermal cycling experiments as well as slow cyclic creep experiments.

Impact Testing Machines: Two Charpy impact machines with capacities ranging from 20 ft-lbs to 240 ft-lbs are available. Accessories include a Dynatup instrumentation package interfaced with an IBM PC, which enables recording of load vs. time traces on bend specimens as well as on tension specimens tested under impact conditions.

Instrumented Microhardness Testing: A Nikon Model QM High-Temperature Microhardness Tester permits indentation studies on specimens tested at temperatures ranging from -196 C to

1600 C under vacuum and inert gas atmospheres. This unit is complemented by a Zwick Model 3212 Microhardness Tester as well as a variety of Rockwell Hardness and Brinell Hardness Testing Machines.

Environmental Stress Laboratories

These facilities include equipment for corrosion, oxidation, and adhesion and wear studies. A wide range of environments can be simulated and controlled a) Aqueous corrosion: atmospheric, immersion and high pressure/high temperature in autoclaves and b) Oxidation: single and mixed gases over a range of temperatures and pressures. Special items include: electrochemical test equipment, environmental cracking test equipment, vacuum equipment for permeation studies, high sensitivity Cahn electrobalances for thermogravimetric studies and polymer/metal adhesion test fixtures.

Transmission Electron Microscope Laboratory

Two transmission electron microscopes are available that provide virtually all conventional and advanced microscopy techniques required for state-of-the-art materials research and involve an installed capacity worth $3,000,000. The microscopes available are (i) an FEI Tecnai F30 300kV field-emission gun energy-filtering high-resolution analytical scanning transmission electron microscope with an information resolution limit better than 0.14nm, equipped with an EDAX system with a high-energy resolution Si-Li detector for X-ray energy-dispersive spectroscopy (XEDS), a Gatan GIF2002 imaging energy filter including a 2k by 2k slow-scan CCD camera, and a high-angle annular dark-field detector for scanning transmission electron microscopy (STEM), and (ii) a Philips CM20 200kV analytical transmission electron microscope equipped with a Tracor Northern high-purity Ge X-ray energy-dispersive spectroscopy detector, a Gatan parallel electron energy-loss spectrometer (PEELS), and a STEM unit.

Conventional TEM techniques, such as bright-field and dark-field imaging, electron diffraction, or weak-beam dark-field imaging (WBDF) are used routinely to analyze line defects (dislocations) and planar defects (interfaces, grain boundaries, stacking faults) in crystalline materials. Advanced TEM techniques include (i) high-resolution TEM, which enables assessing the atomistic structure of crystal defects such as heterophase interfaces, grain boundaries, or dislocations, (ii) convergent-beam electron diffraction, which can be used, for example, to obtain crystallographic information (space group) and to determine orientation relationships between small (even nanoscopic) crystallites, and (iii) energy-filtering TEM, which includes zero-loss filtering for improved image contrast and resolution in conventional imaging and diffraction as well as electron spectroscopic imaging (ESI), a technique that enables rapid elemental mapping with high spatial resolution based on element-characteristic energy losses of the primary electrons in the specimen. Specimen preparation facilities for transmission electron microscopy consist of two dimple-grinders, two electropolishing units, three ultra-microtomes, and two conventional ion-beam mills, and two state-of-the-art precision ion polishing systems (PIPS, by Gatan).

Scanning Electron Microscopy Laboratory

Scanning electron microscopy (SEM) and spectrochemical analysis provide valuable specimen investigation with great depth of field and realistic three-dimensional imaging at resolutions up to 500,000X. Determination of the topography of nearly any solid surface is possible. Spectrochemical studies are possible with the use of energy dispersive systems capable of detecting elements from boron to uranium. The laboratory houses two instruments. The first is an Hitachi S-4500, a field emission electron microscope with two secondary electron detectors, a backscattered electron detector, and an infrared chamber scope. In addition, it has a Noran energy dispersive x-ray detection system. The microscope is capable of operating at a spatial resolution of less than 1.5 nm at 15 kV. It also performs well at reduced beam energies (1 kV), facilitating the observation of highly insulating materials. The second instrument is a Philips XL-30 ESEM with a large chamber that can be used as a conventional SEM, or in the environmental mode, can be used to examine wet, oily, gassy or non-conducting samples. It has a camera for crystallographic orientation imaging, a deformation stage capable of 1000 lbs force, hot stages capable of temperatures up to 1500 C, and a cooling stage that goes down to -20 C. An attached Noran X-ray system permits qualitative and quantitative EDX spectroscopy, X-ray mapping and line scans.

Surface Science Laboratories

The Center for Surface Analysis of Materials (CSAM) enjoys state-of-the-art characterization of metal, alloy, ceramic, and polymer surfaces. These tools include a PHI 660 Scanning Auger Microprobe (SAM) for elemental analysis of surfaces and mapping, and PHI 3600 Secondary Ion Mass Spectrometry (SIMS), which provides surface sensitivities for species in the part per billion range. A PHI model 5400 instrument provides X-ray Photoelectron Spectroscopy (XPS or ESCA) capability, which produces information concerning chemical states. The latter two instruments are particularly useful for ceramic and polymer surfaces. With specimen heating, cooling, and depth profiling capabilities directly incorporated in these devices, subsurface regions and interfaces in composite structures, as well as at thin film substrate interfacial regions, can be examined and fully characterized. The ion beam facility for the analysis of materials consists of a NEC 5SDH 1.7 MV tandem pelletron accelerator for the production of 3.4 MeV protons, 5.1 MeV alpha particles, and N ions with energies in excess of 7.0 MeV. Sample analysis takes place in a turbo-molecular pumped high vacuum chamber. The chamber is equipped with a computer-controlled 5 axis manipulator and has provisions for maintaining sample temperatures from 77 K to 1000 K. A Si surface barrier detector, NaI(Tl) scintillator, and a liquid nitrogen-cooled Si(Li) detector are used to detect scattered ions, characteristic gamma rays and characteristic X-rays, respectively. This instrumentation can non-destructively provide composition and structure information in the near-surface region of materials using techniques such as Rutherford backscattering spectrometry (RBS), ion channeling, particle-induced X-ray analysis (PIXE), and nuclear reaction analysis (NRA). As with other analytic techniques, sensitivity, sampling depth, and depth resolution are sample dependent. However, sensitivities of 1 atomic percent, accuracies of 5%, and a depth resolution of 20 nm are usually easily achieved.

The typical specimen is a solid, vacuum-compatible material with lateral dimensions between 0.5 cm x 0.5 cm and 5 cm x 5 cm. However, PIXE and NRA can also be performed on non-vacuum compatible specimens such as liquids and irreplaceable artifacts of interest to museum curators and archeologists.

Electronic Properties Laboratory

Crystal Growth and Analysis Laboratory

The Crystal Growth and Analysis Laboratory is equipped for research studies and characterization of bulk semiconductor and photonic materials. The growth facilities include a high pressure Czochralski system, low pressure Czochralski system, and a Vertical Bridgman system with magnetic field stabilization. The characterization facilities include capabilities for sample preparation, a Hall effect system, Infra-red microscope, and an Inductively Coupled Plasma-Mass Spectrometer (ICP-MS).

X-Ray Laboratory

The X-ray laboratory contains diffraction equipment for study of the structures of ceramics, metals, polymers, minerals, and single crystals of organic and inorganic compounds. A new Scintag diffractometer system includes a theta/theta wide angle goniometer, a 4.0 kW x-ray generator with copper tube, a third axis stress attachment, a thermoelectrically cooled Peltier germanium detector, a thin film analysis system, a dedicated PC for data acquisition, and a turbomolecular-pumped furnace attachment permitting sample temperatures up to 2000 degrees C.

Materials Science and Engineering (EMSE)

Undergraduate Courses

EMSE C100. Co-Op Seminar I for Materials Science and Engineering (1)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 001.

EMSE C200. Co-Op Seminar II for Materials Science and Engineering (2)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 002 and EMSE C100.

EMSE 102. Materials Seminar (1)
Topical lectures by faculty on current areas of materials research serving to complement the concepts introduced in EMSE 201. General discussion of overall curriculum and educational objectives. Prereq or Coreq: EMSE 201.

EMSE 103. Materials in Sports (3)
The relationships between optimizing sports activities and the performance requirements of sports equipment are developed. The inherent properties of materials are shown to be the controlling factors in the design of almost all types of sports equipment. Properties of the major classes of materials used to manufacture sports equipment are examined. Materials discussed include advanced composites, foams, metals, ceramics, and natural composites, e.g., wood and leather. The absorption, storage, and release of energy by equipment during sports activities are shown to relate to the basic structure of the materials from which it is made. Demonstration experiments are conducted periodically throughout the course.

EMSE 201. Introduction to Materials Science and Engineering (3)
Introductory treatment of crystallography, phase equilibria, and materials kinetics. Application of these principles to examples in metals, ceramics, semiconductors, and polymers, illustrating the control of structure through processing to obtain desired mechanical and physical properties. Design content includes examples and problems in materials selection and of design of materials for particular performance requirements. Prereq: ENGR 145 and PHYS 121 and MATH 121.

EMSE 202. Phase Diagrams and Transformations (3)
Diffusion processes, equilibrium diagrams of alloys: solid solutions, phase mixtures, ordering, intermediate phases, binary and ternary diagrams. Thermodynamic, kinetic, and structural aspects of transformation and reactions in condensed systems. Transformations in alloys: phase transformations near equilibrium, precipitation hardening, martensite reactions. Prereq: EMSE 201.

EMSE 203. Applied Thermodynamics (3)
Basic thermodynamics principles as applied to materials. Application of thermodynamics to material processing and performance including condensed phase and gaseous equilibria, stability diagrams, corrosion and oxidation, electrochemical and vapor phase reactions. Prereq: CHEM 301.

EMSE 270. Materials Laboratory I (2)
Introduction to processing, microstructure and property relationships of metal alloys, ceramics and glass. Solidification of a binary alloy and metallography by optical and scanning electron microscopy. Synthesis of ceramics powders, thermal analysis using TGA and DTA, powder consolidation, sintering and grain growth kinetics. Processing and coloring of glass and glass-ceramics.

EMSE 280. Materials Laboratory II (2)
Synthesis and processing. Experiments designed to demonstrate and evaluate different ways to process different types of materials. Solidification of melts. Crystallization kinetics, processing using electrochemistry, oxidation and oxidized microstructures. Laboratory teams are selected for all experiments.

EMSE 290. Materials Laboratory III (2)
Experiments designed to characterize and evaluate different microstructural designs produced by variations in processing. Fracture of brittle materials, fractography, thermal shock resistance, hardenability of steels, TTT and CT diagrams, composites, solidification of metals, solution annealing of alloys. Prereq: EMSE 201.

EMSE 301. Fundamentals of Materials Processing (3)
Introduction to materials processing technology with an emphasis on the relation of basic concepts to the processes by which materials are made into engineering components. Includes casting, welding, forging, cold-forming, powder processing of metals and ceramics, and polymer and composite processing. Prereq: EMSE 201 and EMSE 202 and EMSE 203.

EMSE 302. Fundamentals of Materials Processing Laboratory (1)
Demonstration of basic processes of materials fabrication. Includes visits to commercial materials processing plants for tours and demonstrations. Graded pass/fail.

EMSE 303. Mechanical Behavior of Materials (3)
Review of elasticity and plasticity. Basic stress strain relationships of single crystal and poly-crystalline materials. Yield criteria. Microstructural factors controlling deformation and fracture of polycrystalline materials. Strengthening mechanisms. Fracture toughness and fatigue behavior of engineering materials. Prereq: EMSE 201 and ENGR 200.

EMSE 307. Foundry Metallurgy (3)
Introduction to solid-liquid phase transformations and their application to foundry and metal casting processes. Includes application of nucleation and growth to microstructural development, application of thermodynamics to molten metal reactions, application of the principles of fluid flow and heat transfer to gating and risering techniques, and introduction to basic foundry and metal casting technology. Prereq: EMSE 202 and EMSE 203 and ENGR 225.

EMSE 310. Applications of Diffraction Principles (1)
A lab sequence in conjunction with EMSE 312, Diffraction Principles, involving experiments on crystallography, optical diffraction, Laue backscattering on single crystals, powder diffraction of unknown compounds, electron diffraction and imaging, and chemical analysis using energy dispersive x-ray spectroscopy. Prereq: EMSE 312 or consent of instructor.

EMSE 312. Diffraction Principles (3)
Use of x-rays, lasers, and electrons for diffraction studies and chemical analysis of materials. Fourier transforms and optical diffraction. Fundamentals of crystallography. Crystal structures of simple metals, semiconductors and ceramics. Reciprocal lattice and diffraction. Stereographic projections. Powder diffraction patterns and analysis of unknown structures. Laue backscattering and orientation of single crystals. Electron microscopy and electron diffraction. Chemical analysis using energy dispersive x-ray spectroscopy. Prereq: EMSE 201 and MATH 224.

EMSE 313. Engineering Applications of Materials (3)
Optimum use of materials taking into account not only the basic engineering characteristics and properties of the materials, but also necessary constraints of component design, manufacture (including machining), abuse allowance (safety factors), and cost. Interrelations among parameters based on total system design concepts. Case history studies. Systems of failure analysis. Prereq: EMSE 202 and ENGR 200.

EMSE 314. Electrical, Magnetic, and Optical Properties of Materials (3)
Materials science of electronic materials and their applications. Topics include: Crystallography of semiconductor materials. Classical and modern theories of electrons in metals. Quantum-mechanical behavior of electrons in solids. Band theory of solids. Boltzmann and Fermi-Dirac statistics. Electronic transport in intrinsic and extrinsic semiconductors. Ohmic and rectifying junctions; diodes, solar cells, and thermoelectric

devices. Types of magnetism; magnetic Curie temperature, domains, and hysteresis. Hard and soft magnetic materials and applications. Dielectric polarization of materials and its frequency dependence. Optical absorption. Optical fibers. Luminescence; phosphors. Prereq: PHYS 122 or PHYS 124.

EMSE 316. Applications of Ceramic Materials (3)
Engineering applications of ceramics. Survey of processing techniques. Thermal and mechanical properties; strength, thermal conductivity, thermal expansion, stress corrosion. Electrical properties: electrical conductivity, dielectric properties, piezo- and ferro-electricity. Glass manufacture and structure-property relationships. Prereq: EMSE 201.

EMSE 360. Transport Phenomena in Materials Science (3)
Review of momentum, mass, and heat transport from a unified point of view. Application of these principles to various phenomena in materials science and engineering with an emphasis on materials processing. Both analytical and numerical methodologies applied in the solution of problems. Prereq: ENGR 225 and MATH 224 or equivalent.

EMSE 396. Special Project or Thesis (1-18)
Special research projects or undergraduate thesis in selected material areas.

EMSE 397. Special Project or Thesis (1-18)
Special research projects or undergraduate thesis in selected material areas.

EMSE 398. Senior Project in Materials I (1)
Independent research project. Projects selected from those suggested by faculty; usually entail original research.

EMSE 399. Senior Project in Materials II (2)
Independent research project. Projects selected from those suggested by faculty; usually entail original research.

Graduate Courses

EMSE 400T. Graduate Teaching I (0)
To provide teaching experience for all Ph.D.-bound graduate students. This will include preparing exams/quizzes, homework, leading recitation sessions, tutoring, providing laboratory assistance, and developing teaching aids that include both web-based and classroom materials. Graduate students will meet with supervising faculty member throughout the semester. Grading is pass/fail. Students must receive three passing grades and up to two assignments may be taken concurrently. Prereq: Ph.D. student in Materials Science and Engineering.

EMSE 401. Transformations in Materials (3)
Review of solution thermodynamics, surfaces and interfaces, recrystallization, austenite decomposition, the martensite transformation and heat treatment of metals. Prereq: EMSE 202.

EMSE 403. Modern Ceramic Processing (3)
Fundamental science and technology of modern ceramic powder processing and fabrication techniques. Powder synthesis techniques. Physical chemistry of aqueous and nonaqueous colloidal suspensions of solids. Shape forming techniques: extrusion; injection molding; slip and tape casting; dry, isostatic, and hot isostatic pressing. Prereq: EMSE 316 (or concur).

EMSE 404. Diffusion Processes in Solids and Melts (3)
Development of the laws of diffusion and their applications. Carburization and decarburization, oxidation processes. Computer modeling of diffusion processing. Prereq: Consent of instructor.

EMSE 405. Dielectric, Optical and Magnetic Properties of Materials (3)
Electrical properties of nonmetals: ionic conductors, dielectrics, ferroelectrics, and piezo-electrics. Magnetic phenomena and properties of metals and oxides, including superconductors. Mechanisms of optical absorption in dielectrics. Optoelectronics. Applications in devices such as oxygen sensors, multilayer capacitors, soft and hard magnets, optical fibers, and lasers. Prereq: Consent of instructor.

EMSE 407. Solidification of Materials (3)
Fundamental science of solid-liquid phase transformations and the application of these basics to the solidification processing of materials. Includes nucleation and growth, heat and solute transport, rapid solidification, and an overview of solidification processing techniques. Emphasis is on the effect of solidification and solidification processing on resulting microstructure. Prereq: EMSE 301.

EMSE 409. Deformation Processing (3)
Flow stress as a function of material and processing parameters; yielding criteria; stress states in elastic-plastic deformation; forming methods: forging, rolling, extrusion, drawing, stretch forming, composite forming. Prereq: EMSE 303.

EMSE 411. Environmental Effects on Materials Behavior (3)
Aqueous corrosion; principles and fundamental concepts; recognition of modes; monitoring and testing; methods to control and prediction. Applications of engineering problems: design, and economics. Mixed potential theory, principles of protection, hydrogen effects, and behavior in metal systems.

EMSE 412. Materials Science and Engineering Seminar (0)

EMSE 413. Fundamentals of Materials Engineering and Science (3)
Provides a background in materials for graduate students with undergraduate majors in other branches of engineering and science: reviews basic bonding relations, structure, and defects in crystals. Lattice dynamics; thermodynamic relations in multi-component systems; microstructural control in metals and ceramics; mechanical and chemical properties of materials as affected by structure; control of properties by techniques involving structure property relations; basic electrical, magnetic and optical properties.

EMSE 417. Properties of Materials at High Temperatures (3)
Thermo physical properties: specific heat, thermal expansion, electrical and thermal conductivity. Temperature dependence of elastic constants. Thermodynamic principles for the stability of microstructures at high temperatures. Strengthening mechanisms. Stress relaxation and damping. Creep deformation. Thermal fatigue and thermal shock. Fracture mechanisms. Refractory metals, superalloys, intermetallic compounds, carbon, ceramic materials. Protective coatings.

EMSE 418. Oxidation of Materials (3)
Experimental techniques; thermodynamics of oxidation reactions; defects and diffusion in oxides; oxidation rate laws. Effects of alloying, surface treatment and stress on oxidation. High-temperature corrosion.

EMSE 419. Phase Equilibria and Microstructures of Materials (3)
The multi-component nature of most material systems require understanding of phase equilibria and descriptions of microstructure. Attention will be given to phase equilibria in multi-component (ternary and higher) systems, and the stereological description of the microstructure of multiphase systems.

EMSE 420. Powder Processing (3)
Fundamental science and technology of modern metal powder processing and fabrication techniques. Includes powder synthesis, characterization, consolidation mechanisms and practices, effects of atmosphere, diffusional homogenization processing, and applications of powder metallurgy.

EMSE 421. Fracture of Materials (3)
Micromechanisms of deformation and fracture of engineering materials. Brittle fracture and ductile fracture mechanisms in relation to microstructure. Strength, toughness, and test techniques. Review of predictive models. Prereq: ENGR 200 and EMSE 303 or EMSE 427; or consent.

EMSE 426. Semiconductor Thin Film Science and Technology (3)
Fundamental science and technology of modern semiconductors. Thin film technologies for electronic materials. Crystal growth techniques. Introduction to device technology. Defect characterization and generation during processing properties of important electronic materials for device applications. Prereq: EMSE 314.

EMSE 427. Dislocations in Solids (3)
Elasticity and dislocation theory; dislocation slip systems; links and dislocation motion; jogs and dislocation interactions, dislocation dissociation and stacking faults; dislocation multiplication, applications to yield phenomena, work hardening and other mechanical properties. Prereq: Consent of instructor.

EMSE 429. Crystallography and Crystal Chemistry (3)
Crystal symmetries, point groups, translocation symmetries, space lattices, crystal classes, space groups, crystal chemistry, crystal structures and physical properties. Prereq: Consent of instructor.

EMSE 500T. Graduate Teaching II (0)
To provide teaching experience for all Ph.D.-bound graduate students. This will include preparing exams/quizzes/homework, leading recitation sessions, tutoring, providing laboratory assistance, and developing teaching aids that include both web-based and classroom materials. Graduate student will meet with supervising faculty member throughout the semester. Grading is pass/fail. Students must receive three passing grades and up to two assignments may be taken concurrently. Prereq: Ph.D. student in Materials Science and Engineering.

EMSE 502. Mechanical Properties of Metals and Composites (3)
Microstructural effects on strength and toughness of advanced metals and composites. Review of dispersion hardening and composite strengthening mechanisms. Toughening of brittle materials via composite approaches such as fiber reinforcement, ductile phases, and combinations of approaches. Prereq: ENGR 200 and EMSE 303 or EMSE 421; or consent.

EMSE 504. Thermodynamics of Solids (3)
Review of the first, second, and third laws of thermodynamics and their consequences. Stability criteria, simultaneous chemical reactions, binary and multi-component solutions, phase diagrams, surfaces, adsorption phenomena.

EMSE 511. Failure Analysis (3)
Methods and procedures for determining the basic causes of failures in structures and components. Recognition of fractures and excessive deformations in terms of their nature and origin. Development and full characterization of fractures. Legal, ethical, and professional aspects of failures from service. Prereq: EMSE 201 and EMSE 303 and ENGR 200; or consent.

EMSE 512. Advanced Electron Microscopy Techniques (3)
Theory and laboratory experiments to learn advanced techniques in transmission electron microscopy; high resolution transmission electron microscopy (HREM), convergent-beam electron microscopy (CBED), and chemical analysis using energy-dispersive x-ray spectroscopy (EDXS) and electron energy-loss spectroscopy (EELS). Prereq: EMSE 515 and EMSE 516.

EMSE 514. Defects in Semiconductors (3)
Presentation of the main crystallographic defects in semiconductors; point defects (e.g., vacancies, interstitials, substitutional and interstitial impurities, line defects (e.g., dislocation), and planar defects (grain boundaries, stacking faults, heteroepitacial interfaces). Structural, electrical and optical properties of various defects. Interpretation of the properties from the perspective of semiconductor physics and materials science and correlation of these defects to physical properties of the material. Experimental methods including TEM, EBIC, CL, DLTS, etc. Prereq: EMSE 426.

EMSE 515. Analytical Methods in Materials Science: Lecture (3)
The common advanced analytical methods used in materials science are TEM, SEM, SAM, SIMS, and ESCA. These acronyms will be defined and the theory and application of each will be explained.

EMSE 516. Analytical Methods in Materials Science/Laboratory (3)
A laboratory course designed to achieve proficiency in TEM, SEM, SIMS, SAM, ESCA, and AFM.

EMSE 600T. Graduate Teaching III (0)
To provide teaching experience for all Ph.D.-bound graduate students. This will include preparing exam/quizzes/homework, leading recitation sessions, tutoring, providing laboratory assistance, and developing teaching aids that include both web-based and classroom materials. Graduate students will meet with supervising faculty member throughout the semester. Grading is pass/fail. Students must receive three passing grades and up to two assignments may be taken concurrently. Prereq: Ph.D. student in Materials Science and Engineering.

EMSE 601. Independent Study (1-18)

EMSE 633. Special Topics (1-18)

EMSE 649. Special Projects (1-18)

EMSE 651. Thesis M.S. (1-18)
Required for Master's degree. A research problem in metallurgy, ceramics, electronic materials, biomaterials or archeological and art historical materials, culminating in the writing of a thesis.

EMSE 701. Dissertation Ph.D. (1-18)
Required for Ph.D. degree. A research problem in metallurgy, ceramics, electronic materials, biomaterials or archeological and art historical materials, culminating in the writing of a thesis.

EMSE 702. Appointed Dissertation Fellow (9)

Department of Mechanical and Aerospace Engineering

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Phone 216-368-2941; Fax 216-368-6445
Joseph M. Prahl, Chair
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The Department of Mechanical and Aerospace Engineering of the Case School of Engineering offers programs leading to bachelors, masters, and doctoral degrees. It administers the programs leading to the degrees of Bachelor of Science in Engineering with a major in aerospace engineering, Bachelor of Science in Engineering with a major in fluid and thermal engineering sciences and Bachelor of Science in Engineering with a major in mechanical engineering. All three curricula are based on four-year programs of preparation for productive engineering careers or further academic training. All three are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

The mission of the Department of Mechanical and Aerospace Engineering is to challenge students to reach towards positions of leadership in the professions of aerospace engineering, fluid and thermal engineering science, and mechanical engineering. The undergraduate program emphasizes fundamental engineering science, analysis and design to insure that graduates will be strong contributors in their work environment, be prepared for advanced study at top graduate schools and be proficient lifelong learners. The graduate programs emphasize advanced methods of analysis, mathematical modeling, computational and experimental techniques applied to a variety of mechanical and aerospace engineering specialties including, applied mechanics, dynamic systems, robotics, biomechanics, fluid mechanics, heat transfer, propulsion and combustion. Leadership skills are developed by infusing the program with current engineering practice, design, and professionalism lead by concerned educators and researchers.

The department's research applies the principles of mechanics, thermodynamics, heat and mass transfer, and engineering design to problems in aeronautics, astronautics, biomechanics and orthopaedic engineering, biomimetics and biological inspired robotics, energy, environment, machinery dynamics, mechanics of materials, and tribology. Many of these activities involve strong collaborations with the departments of biology, electrical engineering and computer science, and orthopaedics of the School of Medicine. The department programs provide

Mastery of Fundamentals

- A strong background in the fundamentals of chemistry, physics and mathematics.
- Methods of mechanical engineering analysis, both numerical and mathematical, applied to mechanics, dynamic systems and control, thermodynamics, fluid mechanics and heat transfer.
- Methods of modern experimental engineering analysis and data acquisition.

Creativity
- Ability to identify, model, and solve mechanical and aerospace engineering design problems.
- Ability to design experiments to resolve mechanical and aerospace engineering issues.
- Ability to perform an individual senior project that demonstrates original research and/or design content.

Societal Awareness
- Issues of environmental impact, efficient use of energy and resources, benefits of recycling.
- An awareness of the multi-disciplinary nature of mechanical and aerospace engineering.
- Impact of economic, product liability and other legal issues on mechanical and aerospace engineering manufacturing and design.

Leadership Skills
- An ability to work in teams.
- Ethical considerations in engineering decisions.
- Proficiency in oral and written communication.

Professionalism
- Students are encouraged to develop as professionals through participation in the student chapters of the American Society of Mechanical Engineers (ASME) and the American Institute of Aeronautics and Astronautics (AIAA).
- Students are encouraged to augment their classroom experiences with the cooperative education program and the strong graduate research program of the department.
- Students are encouraged to take the Fundamentals of Engineering Examination as the first step in the process of becoming a registered professional engineer.

Bachelor of Science in Engineering Degree
Major in Aerospace Engineering

Freshman Year — Class-Lab-Credit Hours

Fall

CHEM 111 Properties and Structure of Matter I	(4-0-4)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
PHYS 121 General Physics I [b]	(4-0-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(14-5-15)**

Spring

MATH 122 Calculus for Science and Engr. II	(4-0-4)
PHYS 122 General Physics II [b]	(4-0-4)
ENGR 145 Chemistry of Materials [a]	(4-0-4)
ENGL 150 Expository Writing	(3-0-3)
PHED 102 Physical Education Activities	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

Humanities or Social Science Sequence I	(3-0-3)
EMAE 172 Mechanical Manufacturing [c]	(3-3-4)
EMAE 181 Dynamics [c]	(3-0-3)
ENGR 200 Introduction to Mechanics [a, c]	(3-0-3)
MATH 223 Calculus for Science & Engineering III	(3-0-3)
EMAE 250 Computers in Mechanical Engineering [c]	(2-2-3)
Total	**(17-5-19)**

Spring

Humanities or Social Science Sequence II	(3-0-3)
ENGR 210 Electronic Circuits [a]	(3-2-4)
PHYS 221 General Physics III	(3-0-3)
MATH 224 Elementary Differential Equations	(3-0-3)
ENGR 225 Introduction to Fluid & Thermal Engr [a]	(4-0-4)
Total	**(16-2-17)**

Junior Year — Class-Lab-Credit Hours

Fall

Humanities or Social Science Sequence III	(3-0-3)
EMAE 325 Fluid and Thermal Engineering II	(4-0-4)
EMAE 282 Mechanical Engineering Lab I	(1-3-2)
ECIV 310 Strength of Materials [c]	(3-0-3)
EMAE 350 Mechanical Engineering Analysis	(3-0-3)
Total	**(14-3-15)**

Spring

Humanities or Social Science Elective	(3-0-3)
EMAE 283 Mechanical Engineering Laboratory II	(1-3-2)
EMAE 359 Aero/Gas Dynamics	(3-0-3)
EMAE 376 Aerostructures	(3-0-3)
ENGL 398N Professional Communication [c]	(3-0-3)
Technical Elective [c]	(3-0-3)
Total	**(16-3-17)**

Senior Year

Fall

Humanities or Social Science Elective	(3-0-3)
EECS 304 Control Engineering I	(3-0-3)
EECS 305 Control Engineering I Laboratory	(0-2-1)
EMAE 381 Flight and Orbital Mechanics	(3-0-3)
EMAE 355 Design of Fluid and Thermal Elements [c]	(3-0-3)
EMAE 360 Engineering Design	(3-0-3)
Total	**(15-2-16)**

Spring

Humanities or Social Science Elective	(3-0-3)
EMAE 356 Aerospace Design	(3-0-3)
EMAE 382 Propulsion	(3-0-3)
EMAE 398 Senior Project [a, c]	(1-6-3)
Open Elective [c]	(3-0-3)
Total	**(13-6-15)**

Hours required for graduation: 129

a. Engineering Core Course
b. Selected students may be invited to take PHYS 123-124, General Physics I, II-Honors (3) in place of PHYS 121-122, General Physics I, II (4).
c. May be taken fall or spring semester.

- The bachelor's candidate must complete an independent design project with an oral and written final report.
- The master's candidate must demonstrate independent research resulting in a thesis or project suitable for publication and/or presentation in peer reviewed journals and/or conferences.
- The doctoral candidate must complete a rigorous independent thesis containing original research results appropriate for publication in archival journals and presentation at leading technical conferences.

Faculty

Joseph M. Prahl, Ph.D. (Harvard University), P.E.
Professor, Chair
Fluid dynamics; heat transfer; tribology.

Maurice L. Adams, Ph.D. (University of Pittsburgh)
Professor
Dynamics of rotating machinery; nonlinear dynamics; vibration; tribology; turbomachinery.

J. Iwan D. Alexander, Ph.D. (Washington State University)
Professor and Chief Scientist for Fluids
National Center for Microgravity Research for Fluids and Combustion
Fluid dynamics; heat and mass transfer, low gravity fluid dynamics, interfacial transport capillary surface equilibria and dynamics, two-phase flow in porous media, vibrational convection

R, Balasubramaniam, Ph.D. (Case Western Reserve University)
Research Associate Professor
National Center for Microgravity Research for Fluids and Combustion
Microgravity Fluid Mechanics

Dwight T. Davy, Ph.D. (University of Iowa), P.E.
Professor
Musculo-skeletal biomechanics; applied mechanics.

Isaac Greber, Ph.D. (Massachusetts Institute of Technology)
Professor
Fluid dynamics; molecular dynamics and kinetic theory; biological fluid mechanics; acoustics.

Bachelor of Science in Engineering Degree
Major in Fluid and Thermal Engineering Sciences

Freshman Year — Class-Lab-Credit Hours

Fall

CHEM 111 Properties and Structure of Matter I	(4-0-4)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
PHYS 121 General Physics I [b]	(4-0-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(17-5-18)**

Spring

MATH 122 Calculus for Science and Engr. II	(4-0-4)
PHYS 122 General Physics II [b]	(4-0-4)
Open Elective or HM/SS Elective	(3-0-3)
ENGR 145 The Chemistry of Materials [a]	(4-0-4)
PHED 102 Physical Education Activities	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall

Humanities or Social Science Sequence I	(3-0-3)
ENGR 200 Introduction to Mechanics [a, c]	(3-0-3)
EMAE 172 Mechanical Manufacturing [c]	(3-3-4)
MATH 223 Calculus for Science & Engineering III	(3-0-3)
EMAE 250 Computers in Mechanical Engineering [c]	(2-2-3)
Total	**(14-5-16)**

Spring

Humanities or Social Science Sequence II	(3-0-3)
EMAE 181 Dynamics [c]	(3-0-3)
MATH 224 Elementary Differential Equations	(3-0-3)
ENGR 225 Introduction to Fluid & Thermal Engr [a]	(4-0-4)
Science Elective [c]	(3-0-3)
Total	**(16-0-16)**

Junior Year — Class-Lab-Credit Hours

Fall

Humanities or Social Science Sequence III	(3-0-3)
EMAE 325 Fluid and Thermal Engineering II	(4-0-4)
EMAE 152 Thermodynamics II	(3-0-3)
EMAE 282 Mechanical Engineering Lab I	(1-3-2)
EMAE 350 Mechanical Engineering Analysis	(3-0-3)
Total	**(14-3-15)**

Spring

Humanities or Social Science Sequence Elective	(3-0-3)
ENGR 210 Electronic Circuits [a]	(3-2-4)
EMAE 283 Mechanical Engineering Laboratory II	(1-3-2)
EMAE 359 Aero/Gas Dynamics	(3-0-3)
Technical Elective [c]	(3-0-3)
Total	**(13-5-15)**

Senior Year

Fall

Humanities or Social Science Elective	(3-0-3)
EECS 304 Control Engineering I	(3-0-3)
EECS 305 Control Engineering I Laboratory	(0-2-1)
EMAE 355 Design of Fluid and Thermal Elements [c]	(3-0-3)
EMAE 360 Engineering Design	(3-0-3)
Technical Elective [c]	(3-0-3)
Total	**(15-2-16)**

Spring

Humanities or Social Science Elective	(3-0-3)
EMAE 356 Aerospace Design	(3-0-3)
EMAE 398 Senior Project [a, c]	(1-6-3)
ENGL 398N Professional Communication [c]	(3-0-3)
Technical Elective [c]	(3-0-3)
Open Elective [c]	(3-0-3)
Total	**(16-6-18)**

Hours required for graduation: 129

a. Engineering Core Course
b. Selected students may be invited to take PHYS 123-124, General Physics I, II-Honors (3) in place of PHYS 121-122, General Physics I, II (4).
c. May be taken fall or spring semester.

Jaikrishnan R. Kadambi, Ph.D. (University of Pittsburgh)
Professor
Experimental fluid mechanics; multiphase flows; laser diagnostics; biological fluid mechanics; turbomachinery; heat transfer.

Yasuhiro Kamotani, Ph.D. (Case Western Reserve University)
Professor
Experimental fluid dynamics; heat transfer; microgravity fluid mechanics.

Mohammad Kassemi, Ph.D. (Akron)
Research Associate Professor
National Center for Microgravity Research for Fluids and Combustion
Computational Fluid Mechanics

Thomas P. Kicher, Ph.D. (Case Institute of Technology)
Arthur P. Armington Professor of Engineering
Elastic stability; plates and shells; composite materials; dynamics; design; failure analysis.

Joseph M. Mansour, Ph.D. (Rensselaer Polytechnic Institute)
Professor, Associate Dean of Graduate Studies and Research, The Case School of Engineering
Biomechanics; applied mechanics.

Simon Ostrach, Ph.D. (Brown University), P.E.
Wilbert J. Austin Distinguished Professor of Engineering and Director of the National Center for Microgravity Research on Fluids and Combustion
Fluid mechanics; heat transfer; micro-gravity phenomena; materials processing; physicochemical hydrodynamics.

Vedha Nayagam, Ph.D. (University of Kentucky)
Research Associate Professor
National Center for Microgravity Research for Fluids and Combustion
Low gravity combustion and fluid physics.

Bachelor of Science in Engineering Degree Major in Mechanical Engineering

Freshman Year

Fall	Class-Lab-Credit Hours
CHEM 111 Properties and Structure of Matter I	(4-0-4)
MATH 121 Calculus for Science and Engineering I	(4-0-4)
PHYS 121 General Physics I [b]	(4-0-4)
ENGR 131 Elementary Computer Programming	(2-2-3)
ENGL 150 Expository Writing	(3-0-3)
PHED 101 Physical Education Activities	(0-3-0)
Total	**(17-5-18)**

Spring	
MATH 122 Calculus for Science and Engr. II	(4-0-4)
PHYS 122 General Physics II [b]	(4-0-4)
Open Elective or HM/SS Elective	(3-0-3)
ENGR 145 The Chemistry of Materials [a]	(4-0-4)
PHED 102 Physical Education Activities	(0-3-0)
Total	**(15-3-15)**

Sophomore Year

Fall	
Humanities or Social Science Sequence I	(3-0-3)
ENGR 200 Introduction to Mechanics [a, c]	(3-0-3)
EMAE 172 Mechanical Manufacturing [c]	(3-3-4)
MATH 223 Calculus for Science & Engineering III	(3-0-3)
EMAE 250 Computers in Mechanical Engineering [c]	(2-2-3)
Total	**(14-5-16)**

Spring	
Humanities or Social Science Sequence II	(3-0-3)
EMAE 181 Dynamics [c]	(3-0-3)
MATH 224 Elementary Differential Equations	(3-0-3)
ENGR 225 Introduction to Fluid & Thermal Engr [a]	(4-0-4)
Science Elective [c]	(3-0-3)
Total	**(16-0-16)**

Junior Year

Fall	Class-Lab-Credit Hours
Humanities or Social Science Sequence III	(3-0-3)
EMAE 325 Fluid and Thermal Engineering II	(4-0-4)
EMAE 282 Mechanical Engineering Lab I	(1-3-2)
ECIV 310 Strength of Materials [c]	(3-0-3)
EMAE 350 Mechanical Engineering Analysis	(3-0-3)
Total	**(14-3-15)**

Spring	
Humanities or Social Science Elective	(3-0-3)
ENGR 210 Electronic Circuits [a]	(3-2-4)
EMAE 271 Kinematic Analysis and Synthesis	(2-2-3)
EMAE 283 Mechanical Engineering Laboratory II	(1-3-2)
EMAE 370 Design of Mechanical Elements	(3-0-3)
Technical Elective [c]	(3-0-3)
Total	**(15-7-18)**

Senior Year

Fall	
Humanities or Social Science Elective	(3-0-3)
EECS 304 Control Engineering I	(3-0-3)
EECS 305 Control Engineering I Laboratory	(0-2-1)
EMAE 355 Design of Fluid and Thermal Elements [c]	(3-0-3)
EMAE 360 Engineering Design	(3-0-3)
EECS 352 Engr Econ and Dec Making	(3-0-3)
Total	**(15-2-16)**

Spring	
Humanities or Social Science Elective	(3-0-3)
Technical Elective	(3-0-3)
EMAE 398 Senior Project [a, c]	(1-6-3)
ENGL 398N Professional Communication [c]	(3-0-3)
Technical Elective [c]	(3-0-3)
Total	**(13-6-15)**

Hours required for graduation: 129

a. Engineering Core Course
b. Selected students may be invited to take PHYS 123-124, General Physics I, II-Honors (3) in place of PHYS 121-122, General Physics I, II (4).
c. May be taken fall or spring semester.

Vikas Prakash, Ph.D. (Brown University)
Associate Professor
Experimental and computational solid mechanics; dynamic deformation and failure; time resolved high-speed friction; ultra-high speed manufacturing processes; ballistic penetration of superalloys; engine fan-blade containment.

Roger D. Quinn, Ph.D. (Virginia Polytechnic Institute & State University)
Professor
Biologically inspired robotics; agile manufacturing systems; structural dynamics, vibration and control.

Clare M. Rimnac, Ph.D. (Lehigh University)
Associate Professor and Director, Musculoskeletal Mechanics and Materials Laboratories
Biomechanics; fatigue and fracture mechanics.

Chih-Jen Sung, Ph.D. (Princeton University)
Associate Professor
Combustion; propulsion; laser diagnostics.

Approved Technical Electives

EMAE The following list of technical electives has been established for both the Fluid and Thermal Engineering Sciences Program and the Mechanical Engineering Program. The courses must be selected to provide a minimum of two additional design credits for each program. Once the design credit minimum is met, the technical electives can be selected from the list of Approved Technical Electives for students of the Department and must be approved by the student's adviser to insure a coherent program of courses to meet the student's professional objectives.

Design Electives

Fluid and Thermal Engineering Science Program

EMAE 271 Kinematic Analysis & Synthesis
EMAE 370 Design of Mechanical Elements

Mechanical Engineering Program

EMAE 152 Thermodynamics II
EMAE 356 Aerospace Design
EMAE 359 Aero/Gas Dynamics

All Programs

EMAE 372 Relation of Materials to Design
EMAE 376 Aerostructures
EMAE 378 Mechanics of Machinery I
EMAE 387/487 Vibration Problems in Engr.
EMAE 381 Flight and Orbital Mechanics
EMAE 382 Propulsion

Technical Electives

Aerospace

EMAE 356 Aerospace Design
EMAE 359 Aero/Gas Dynamics
EMAE 376 Aerostructures
EMAE 381 Flight and Orbital Mechanics
EMAE 382 Propulsion

Biomechanics

EBME 201 Physiology-Biophysics I
EBME 202 Physiology-Biophysics II
EBME 306 Introduction to Biomedical Materials
EBME 309 Modeling of Biomedical Systems
EBME 310 Principles of Biomedical Instrumentation
EMAE 402 Muscles, Biomechanics and Control of Movement
EMAE 415 Introduction to Musculo-skeletal Biomechanics

Digital Electronics and Control

EECS 245 Electronic Circuits
EECS 246 Circuits, Signals & Systems II
EECS 304 Control Engr. I
EECS 281 Logic Design and Computer Organization
EECS 382 Microprocessor-based Design

Dynamics and Vibration

EMAE 378/478 Mechanics of Machinery I
EMAE 387/487 Vibration Problems in Engineering
EMAE 479 Mechanics of Machinery II
EMAE 481 Advanced Dynamics I
EMAE 484 Mechanisms and Motion Synthesis

Fluid and Thermal Engineering

EMAE 152 Thermodynamics II
EMAE 359 Aero/Gas Dynamics
EMAE 453 Advanced Fluid Dynamics I
EMAE 460 Theory & Design of Fluid Power Machinery

Fluid and Thermal Sciences

EMAE 453 Advanced Fluid Dynamics I
EMAE 454 Advanced Fluid Dynamics II
EMAE 455 Advanced Thermodynamics
EMAE 457 Combustion

Mathematics and Statistics

MATH 323 Advanced Calculus
MATH 324 Introduction to Complex Analysis
MATH 331 Computational Linear Algebra
STAT 312 Statistics for Engr & Sci.
STAT 333 Uncertainty in Engr & Sci

Materials

EMSE 301 Fundamentals of Materials Processing
EMSE 303 Mechanical Behavior of Materials
EMSE 307 Foundry Metallurgy
EMSE 313 Engineering Applications of Materials
EMAE 473 Mechanical Behavior of Composite Materials
EMAE 480 Fatigue of Materials

Mechanical Design

EMAE 372 Relations of Materials to Design
EMAE 471 Design Methods
EMAE 472 Computers, Optimization and Design

Mechanical Manufacturing

EMAE 290 Computer Aided Manufacturing
EMAE 390 Advanced Manufacturing
EECS 350 Production and Operational Systems
EECS 360 Manufacturing and Integrated Systems
OPMT 350 Operations Management
OPMT 352 Design of Production Systems
OPRE 201 Introduction to Operations Research I

Solid Mechanics

ECIV 220 Structural Analysis I
ECIV 221 Structural Design I
EMAE 372 Relation of Materials to Design
EMAE 376 Aerostructures
ECIV 410 Advanced Strength of Materials
EMAE 473 Mechanical Behavior of Composite Material
EMAE 480 Fatigue of Materials

Fumiaki Takahashi, Ph.D. (Keio University)
Research Associate Professor
National Center of Microgravity Research for Fluids and Combustion
Combustion, fire research, laser diagnostics.

James S. T'ien, Ph.D. (Princeton University)
Professor and Chief Scientist for Combustion
National Center for Research for Fluids and Combustion
Combustion; propulsion, and microgravity fire research

Edward B. White, Ph.D. (Arizona State University)
Assistant Professor
Experimental fluid mechanics, fluid stability

Associated Faculty

Roberto Ballarini, Ph.D. (Northwestern University)
Professor of Civil Engineering
Experimental and analytical studies of fatigue and fracture mechanics.

Christos C. Chamis, Ph.D. (Case Western Reserve University)
Adjunct Professor
NASA Glenn Research Center
Structural analysis; composite materials; probabilistic structural analysis; testing methods.

Malcolm N. Cooke, M.Sc. (University of Warwick, U.K.)
Adjunct Assistant Professor
Advanced manufacturing systems; computer integrated manufacturing.

Robert V. Edwards, Ph.D. (The Johns Hopkins University)
Professor of Chemical Engineering
Laser anemometry; mathematical modeling; data acquisition.

David Fyhrie, Ph.D. (Stanford University)
Adjunct Assistant Professor
H. Ford Hospital-biomechanics.

Kenneth Loparo, Ph.D. (Case Western Reserve University)
Professor of Electrical Engineering and Computer Science
Control; robotics; stability of dynamical systems; vibrations.

David Matthiesen, Ph.D. (Massachusetts Institute of Technology)
Associate Professor of Materials Science & Engineering
Microgravity crystal growth.

Robert L. Mullen, Ph.D. (Northwestern University)
Professor and Chair of Civil Engineering
Computational mechanics; finite elements; interface mechanics.

Wyatt S. Newman, Ph.D. (Massachusetts Institute of Technology)
Professor of Electrical Engineering and Computer Science
Mechatronics; high-speed robot design; force and vision-bases machine control; artificial reflexes for autonomous machines; rapid prototyping; agile manufacturing.

Eli Reshotko, Ph.D. (California Institute of Technology)
Kent H. Smith Emeritus Professor of Engineering
Fluid Dynamics; heat transfer, propulsion;; power generation

Lev A. Slobozhanin, Dr. Sci. (A.S., USSR), Ph.D. (A.S., Ukraine)
Principal Researcher
Mathematical Physics and physics of fluids, stability of interfaces

Melissa Louis Knothe Tate, Ph.D.(U. & Swiss Federal I.T.)
Adjunct Assistant Professor
Department of Biomedical Engineering, Cleveland Clinic Foundation
Mechanobiology of musculoskeletal systems, orthopaedic biomechanics, implant design, cellular and biofluid mechanics

Uday Hegde, Ph.D. (Georgia Institute of Technology)
Principal Researcher
National Center for Microgravity Research for Fluids anfd Combustion
Microgravity fluid mechanics and combustion

Ravi Vaidyanathan, Ph.D. (Case Western Reserve University)
Adjunct Assistant Professor
Robotics and control

Harold Wachman, Ph.D. (University of Missouri)
Adjunct Professor, Professor Emeritus (Massachusetts Institute of Technology)
Low density gas behavior; molecular dynamics.

Caroline A. Whitbeck, Ph.D. (Massachusetts Institute of Technology)
Elmer Beamer-Hubert Schneider Chair of Ethics and Professor of Philosophy
Practical & professional ethics; research ethics; philosophy of science, engineering, medicine; feminist philosophy

Aerospace Engineering

Aerospace engineering has grown dramatically with the rapid development of the computer in experiments, design and numerical analysis. The wealth of scientific information developed as a result of aerospace activity forms the foundation for the aerospace engineering major.

Scientific knowledge is being developed each day for programs to develop reusable launch vehicles (RLV), the International Space Station (ISS), High Speed Transport (HST), Human Exploration and Development of Space (HEDS) and micro-electro-mechanical sensors and control systems for advanced flight. New methods of analysis and design for structural, fluid, and thermodynamic applications are required to meet these challenges.

The aerospace engineering major has been developed to address the needs of those students seeking career opportunities in the highly specialized and advancing aerospace industries.

Fluid and Thermal Engineering Sciences

The fluid and thermal engineering sciences are significant not only for modern technology but also for many phenomena related to the association of man with his environment. The importance of this field to aeronautics and astronautics is readily apparent, but it is also of critical importance to many industrial manufacturing processes, power generation and lubrication.

Physicochemical transport phenomena is a subject that has developed at the interface between physics and chemistry, and is concerned with problems raised by the effects of fluid motions on chemical and physicochemical transformations and by the effect of physicochemical factors on the motion of fluids. This subject has considerable significance to microgravity fluids and combustion processes that will be critical to sustaining life for manned space exploration and to many important industrial processes on earth such as materials processing; electrochemical processes; energy storage; pollution; oil recovery; and biological, physiological, and geological phenomena.

The educational program in fluid and thermal engineering sciences takes cognizance of a broad scope of applications and is fundamental and comprehensive. The interdisciplinary nature of the field is continually stressed, and the subject matter is made relevant to current research and development.

Mechanical Engineering

Civilization, as we know it today, depends on the intelligent and humane use of our energy resources and machines. The mechanical engineer's function is to apply science and technology to the design, analysis, development, manufacture, and use of machines that convert and transmit energy, and to apply energy to the completion of useful operations. The top ten choices of the millennium committee of the National Academy of Engineering, asked to select the 20 top engineering accomplishments of the 20th century, was abundant with mechanical engineering accomplishments, electrification (large scale power generation and distribution), automobiles, air travel (development of aircraft and propulsion), mechanized agriculture, and refrigeration and air conditioning.

5-Year Programs of Study

The department curriculum offers a five-year cooperative (co-op) education program and five- year combined bachelors-masters programs. Co-op weaves two 7-month industrial internships into the normal four-year program by combining a summer with either a fall or spring semester to form the 7-month industrial experiences. Students apply to participate in the middle of the sophomore year and nominally begin the internship in the spring semester of the junior year. After completing the second internship, students return to campus in the spring or fall to complete their final year of study.

Alternative to the co-op 5 year program, is the 5 year combined bachelors/masters program in which a student can, by double counting 9 credit hours, complete a bachelor of science degree in anyone of the department's three degree programs as well as a master of science degree in mechanical and aerospace engineering with a thesis by the end of the fifth year. Application to this program is initiated in the spring of the junior year with the department's graduate student programs office. A minimum grade point of 3.2 is required for consideration for this accelerated program.

Graduate Programs

Master of Science Program

Each M.S. candidate must complete a minimum of 27 hours of graduate-level credits. These credits can be distributed in one of two ways.

Plan A

Students electing Plan A take 18 hours of graduate-level courses and complete at least 9 credit hours of M.S. thesis research.

Plan B

Plan B is directed primarily to part-time students whose technical work in industry or government laboratories is suitable for project courses. Plan B requires completion of 27 credit hours distributed in either of two ways 21 or 24 credit hours (seven or eight courses) of approved graduate course work and 6 or 3 credit hours of project replacing the M.S. thesis.

Master of Engineering Program

The Department of Mechanical and Aerospace Engineering participates in the practice-oriented Master of Engineering program offered by the Case School of Engineering. In this program, students complete a core program consisting of five courses, and select a four-course sequence in an area of interest.

Doctor of Philosophy Program

Students wishing to pursue the doctoral degree in mechanical and aerospace engineering must successfully pass the doctoral qualifying examination consisting of both written and oral components. Qualifying exams are offered on applied mechanics, dynamics and design or fluid and thermal engineering sciences. Students can chose to take it at the beginning of fall or spring semesters. The minimum course requirements for the Ph.D. degree are as follows:

Depth Courses

All programs of study must include 6 graduate level mechanical courses in mechanical engineering or closely related engineering disciplines. Usually these courses follow a logical development of a branch of mechanics, dynamics and design or fluid and thermal engineering science determined in conjunction with the student's thesis advisor to meet the objectives of the thesis research topic.

Breadth and Basic Science Courses

A minimum of six courses outside the department must be taken. These can be chosen from other engineering departments and the departments of mathematics and natural science. A minimum of two elective courses must be in mathematics.

Thesis research

All doctoral programs must include a minimum of 18 credit hours of thesis research, EMAE 701.

Residence and teaching requirements

All doctoral programs require a minimum of one year of full-time residence in the program of study, three semesters of teaching experience, and must meet the rules of the School of Graduate Studies and the Case School of Engineering.

Facilities

The education and research philosophy of the Department of Mechanical and Aerospace Engineering for both the undergraduate and graduate programs is based on a balanced operation of analytical, experimental, and computational activities. All three of these tools are used in a fundamental approach to the professional activities of research, development, and design. Among the major assets of the department are the experimental facilities maintained and available for the faculty, students, and staff.

The introductory undergraduate courses are taught through the Robert M. Ward '41 Laboratory, the Reinberger Product and Process Development Laboratory, the Alden Laboratory for Numerically Controlled Machine Instruction and the General Motors Design Studio. The Ward Laboratory is modular in concept and available to the student at regularly scheduled class periods to conduct a variety of prepared experimental assignments. The lab is equipped with a variety of instruments ranging from classic analog devices to modern digital computer devices for the collection of data and the control of processes. Advanced facilities are available for more specialized experimental tasks in the various laboratories dedicated to each specific discipline. Most of these laboratories also house the research activities of the department, so students are exposed to the latest technology in their prospective professional practice. Finally, every undergraduate and graduate degree program involves a requirement, i.e., Project, Thesis or Dissertation, in which the student is exposed to a variety of facilities of the department.

The following is a listing of the major laboratory facilities used for the advanced courses and research of the department.

Biorobotics Laboratory Facilities

The Biorobotics Laboratory (http//biorobots.cwru.edu/) consists of approximately 1080 square feet of laboratory and 460 square feet of office space. The lab includes two CNC machines for fabrication of smaller robot components. The lab's relationship with CAISR (Center for Automation and Intelligent Systems Research) provides access to a fully equipped machine shop where larger components are fabricated. The laboratory hardware features several biologically inspired hexapod robots including two cockroach-like robots, Robot III and Robot IV. Both are based on the *Blaberus* cockroach and have 24 actuated revolute joints. They are a 17 times larger than the insect (30 inches long) . Robot IV is actuated with pneumatic artificial muscles. A compressed air facility has been installed to operate the robots. In addition, the lab contains structural dynamic testing equipment (sensors, DAQ boards, shakers) and an automated treadmill (5 feet by 6 feet) for developing walking robots. The Biorobotics Laboratory contains 20 PCs, and a dedicated LAN connected to the campus. Algor Finite Element Analysis software, Mechanical Desktop, and Pro/ Engineer are installed for mechanical design and structural analysis. Also, the lab has developed dynamic simulation software for analyzing walking animals and designing walking robots.

Combustion Diagnostics Laboratory

The combustion diagnostics laboratory is directed towards the experimental and computational investigation of combustion and propulsion phenomena to gain insights into efficient and environment-friendly combustion. Research activities are conducted via state-of-the-art non-intrusive laser-based diagnostic techniques, computation with detailed chemistry and transport, and mathematical analysis of flame structure and dynamics, with strong coupling between the individual components. The laboratory is equipped to conduct laser diagnostics measurements, including Spontaneous Raman Spectroscopy, Planar Laser Induced Fluorescence, Raleigh Scattering, Coherent Anti-Stoke Raman Spectroscopy, and Particle Imaging Velocimetry. Current projects include laser diagnostics of reacting and non-reacting flows, aerodynamics and chemical structure of flames, ignition and flame stabilization in supersonic flows, development of reduced chemistry, soot and NOx formation, microgravity combustion, emission reduction in internal combustion engines, and advanced propulsion systems.

Laser Flow Diagnostics Laboratory

A laser diagnostics laboratory is directed toward investigation of complex two-phase flow fields involved in energy-related areas, fluid mechanics of the heart, and slurry flow in pumps and spray characterization. The laboratory is equipped with state of the art Particle Image Velocimetry (PIV) equipment, phase Doppler and laser Doppler anemometers and modern data acquisition and analysis equipment including PCs. The laboratory houses a pulsatile flow loop simulating flow through the heart, a clear centrifugal slurry flow pump loop, and a particle laden jet facility simulating flow in fossil fuel flue gas flow conditions. Current research projects include investigation of flow through heart valves, development of simultaneous particle/droplet size and velocity measurement technique using PIV, development of innovative nozzles for sorbent laden flows for removal of toxins from flue gas, solid-slurry flow through centrifugal pump impellers.

The National Center for Microgravity Research on Fluids and Combustion

The mission of the National Center for Microgravity Research on Fluids and Combustion is to lead a national effort to increase both the number and quality of microgravity researchers. The Center will perform the critical-path research in microgravity fluids and combustion sciences necessary to support the long-term human presence, development and exploration of space as well as to enhance life on Earth by applying the resultant advances in human knowledge and technology acquired through experimentation in the space environment. The Center is dedicated to research in fluid mechanics, heat transfer and combustion in microgravity, such as that found on Shuttle flights, the International Space Station, and long-duration space flight. This activity is directed toward a fundamental understanding of thermocapillary flow, double-diffusive convection, convection in the float-zone crystal growth process, various types of combustion phenomena and spacecraft fire safety.

Mechanics of Materials Experimental Facility

The major instructional as well as research facility for experimental methods in mechanics of materials is the Daniel K. Wright, Jr. Laboratory. Presently, the facility houses a single-stage gas-gun along with tension/compression split Hopkinson bar and torsional Kolsky bar apparatus for carrying out fundamental studies in dynamic deformation and failure of advanced material systems. Hewlett Packard and Tektronix high speed, wide bandwidth digitizing oscilloscopes along with strain-gage conditioners and amplifiers are available for data recording and processing. The facility houses state-of-the-art laser interferometry equipment for making spatial and temporal measurements of deformation. High speed Hg-Cd-Te detector arrays are available for making time resolved multi-point non-contact temperature measurements.

A Schenck Pegasus digital servo-controlled hydraulic testing system with a 20Kip Universal testing load frame equipped with hydraulic grips and instrumentation is available for quasi-static mechanical testing under load or displacement control. A newly developed moirémicroscope is available for studying large-scale inelastic deformation processes on micron size scales. CCD camera along with the appropriate hardware/software for image-acquisition, processing and analyzing of full field experimental data from optical interferometers such as moiré microscope, photo-elasticity, and other laser based spatial interferometers are available.

Rotating Machinery Dynamics and Tribology Laboratory

This laboratory focuses on rotating machinery monitoring and diagnostic methods relating chaos content of dynamic non-linearity and model-based observers' statistical measures to wear and impending failure modes. A double-spool-shaft rotor dynamics test rig provides independent control over spin speed and frequency of an adjustable magnitude circular rotor vibration orbit for bearing and seal rotor-dynamic characterizations.

Simultaneous radial and axial time-varying loads on any type of bearing can be applied on a second test rig. Real time control of rotor-mass unbalance at two locations on the rotor while it is spinning up to 10,000 rpm, simultaneous with rotor rubbing and shaft crack propagation, can be tested on a third rig. Self-excited instability rotorvibrations can be investigated on a fourth test rig.

Musculoskeletal Mechanics and Materials Laboratories

These laboratories are a collaborative effort between the Mechanical and Aerospace Engineering Department of the Case School of Engineering and the Department of Orthopaedics of the School of Medicine. The program has its origins in the pioneering research in musculoskeletal biomechanics of Dr. Victor Frankel and Dr. Albert Burstein, who began their research activities at the University in the 1960's. Research activities have ranged from basic studies of mechanics of skeletal tissues and skeletal structures, experimental investigation of prosthetic joints and implants, measurement of musculoskeletal motion and forces, and theoretical modeling of mechanics of musculoskeletal systems. Many studies are collaborative, combining the forces of engineering, biology, biochemistry, and surgery. The Biomechanics Test labs include Instron mechanical test machines with simultaneous axial and torsional loading capabilities, a non-contacting video extensometer for evaluation of biological materials and engineering polymers used in joint replacements, acoustic emission hardward and software, and specialized test apparatus for analysis of joint kinematics. An Orthopaedic Implant Retrieval Analysis lab has resources for characterization and analysis of hard tissues and engineering polymers, as well as resources to maintain a growing collection of retrieved total hip and total knee replacements that are available for the study of implant design. There are also a Soft Tissue-testing lab with several standard and special test machines, an Instrumentation Laboratory, and a Biomechanical Computations and Design lab.

CWRU Low Speed Research Wind Tunnel

The CWRU Low Speed Research Wind Tunnel has completed a major rebuilding effort during which flow quality, instrumentation, operability, flexibility, and noise and vibration levels, have been significantly improved. The tunnel provides very low freestream turbulence levels, making it suitable for highly sensitive boundary-layer stability experiments that require excellent flow quality. The tunnel is completely modular, allowing a variety of different experimental configurations to be realized, greatly extending the tunnel's functionality.

The tunnel, originally constructed in the late 1940's, has undergone a rebuilding effort with the construction of a new test section, the replacement of the entire upstream half of the wind tunnel, the rebuild of the drive section, and installation of a new drive motor and motor controller. The new upstream portion provides the incoming flow treatment necessary to produce a low freestream turbulence level. The improved drive section and motor increase the tunnel's maximum speed while reducing noise and vibration levels. With these improvements, the tunnel now supports research of the highest quality.

Other Experimental Facilities

The department facilities also include several specialized laboratories

- The GM Engines Laboratory is a modern facility for measuring the dynamic performance of internal combustion engines while monitoring behavioral parameters such as pressures, temperatures and exhaust emissions. The test cells can be operated completely by remote control with all data collected by digital computers.
- The Structural Dynamics Laboratory was developed with a grant from NSF and includes facilities for performing vibration and modal testing. This equipment includes laser vibrometers, accelerometers, electrodynamic shakers, computers and data acquisition systems.
- In association with the Department of Electrical Engineering and Computer Science we have agile manufacturing facilities including flexible parts feeders of our design.
- Well-equipped, manned central shops and instrument rooms are available, as well as a controlled-environment room for experiments requiring extreme precision.

Graphical and Computational Facilities

The Computer-Aided Engineering Laboratory (CAEL) includes 18 Dell 500MHz Pentium III computers attached to a Dell dual 500 MHz Pentium III server, running Windows NT 4.0, via local area network running at 100 Mb/s. The CAEL provides access to a number of software packages. Some of these include Pro/Engineer, Release 2000i; Visual Fortran, Release 6.0; AutoCAD, Release 13; Matlab, Release 5.3; and Microsoft Office 2000 Professional. All of the laboratory's computers are directly linked to the campus network giving students access to a large variety of software on different libraries across campus. The lab is open for student use 7 days a week from 600 a.m. through midnight via card access.

The General Motors Design Studio includes 13 Dell 400MHz Pentium II workstations and 6 Net Power 233MHz Pentium II workstations. These machines are connected via local network to a Dell Dual 333MHz Pentium II server running Windows NT 4.0. The GM Lab is tied directly to the campus network allowing information to be shared with the CAEL. The GM Design Studio is used for instruction on Pro/Engineer CAD/CAM software, and offers a Rapid Prototyping Machine for creating wax models from Pro/Engineer models.

Supercomputing

The department has recently been awarded an 8-node, 32-processor Beowulf-class computing cluster by the Ohio Supercomputer Center. The cluster features libraries, compilers, and debuggers specifically designed for computationally intensive numerical simulations and parallel-code development. Extensive data visualization tools are also available on the cluster. The department also has access to all NSF supercomputing centers, primarily the Pittsburgh and Ohio Supercomputing Centers. Research projects carried on in cooperation with NASA Glenn Research Center can have access to NASA computing facilities.

Research

The research in the department encompasses many areas of modern technology. Among them are:

Aerospace Technology and Transportation

Aerospace mechanics, aircraft aerodynamics (subsonic, supersonic and hypersonic), stability and transition of boundary layers and free shear layers, flow in turbomachinery, molecular dynamics simulation of rarefied gas flow, two phase flow, supersonic combustion and control of internal combustion engines.

Combustion

Flame spread, microgravity combustion, fire research, chemical kinetic models and pollutant formation.

Dynamics of Rotating Machinery

Forced and instability vibration of rotor/bearing/seal systems, nonlinear rotor dynamics, torsional rotor vibration, rotor dynamic characteristics of bearings and seals (computational and experimental approach), control of rotor system dynamics, rub-impact studies on bearings and compressor/turbine blading systems. Advanced rotating machinery monitoring and diagnostics.

Engineering Design

Optimization and computer-aided design, feasibility studies of kinematic mechanisms, kinematics of rolling element-bearing geometries, mechanical control systems, experimental stress analysis, failure analysis, development of biologically inspired methodologies.

Manufacturing

Agile manufacturing work cells developed to facilitate quick change over from assembly of one object to assembly of other objects contains multiple robots, a conveyor system and flexible parts feeders.

Materials

Development of novel experimental techniques to investigate material response at elevated temperatures and high rates of deformation. Constitutive modeling of damage evolution, shear localization and failure of advanced engineering materials. Fabrication of mechanical properties of composite materials; creep, rupture, and fatigue properties of engineering materials at elevated temperatures.

Microgravity Research

Gravitational effects on transport phenomena, fluids and thermal processes in advance life support systems for long duration space travel, interfacial processes, g-jitter effects on microgravity flows, two phase flow in zero and reduced gravity. Combustion phenomena in microgravity, spacecraft fire safety.

Multiphase Flow Research

Application of non-intrusive laser based diagnostic techniques to study solid-liquid, solid-gas, liquid-gas and solid-liquid-gas, multiphase flows encountered in slurry transport, flue gas desulfurization processes, spray diagnostics and bio-fluid mechanics.

Orthopaedic Engineering

Kinematics and mechanical joint dynamics of the knee, hip, ankle, and spine; dynamic stability of the human spine; neuromuscular control; mechanics of injuries; gait analysis; design and failure analysis of medical prostheses and material selection; biomechanical measurements, tools and instrumentation; mechanical properties of bone and soft tissue.

Robotics

Biologically inspired and biologically based design and control of legged robots. Dynamics, control and simulation of animals and robots.

Tribology

Time-resolved friction on nano- and microsecond time scale with applications to high speed machining and mechanics of armor penetration. Study of gas lubricated foil bearing systems and magnetic bearing systems with application to oil-free turbomachinery. Retainerless bearings for space applications such as long duration instrument and guidance systems and momentum wheels.

Turbomachinery

Vibration characteristics of seals and bearings and measurement of chaotic motion. Rub impact studies of blade tip/casing interactions, particle-blade/casing interactions in centrifugal pumps.

Mechanical and Aerospace Engineering (EMAE)

Undergraduate Courses

EMAE C100. Co-Op Seminar I for Mechanical Engineering (1)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 001.

EMAE C200. Co-Op Seminar II for Mechanical Engineering (2)
Professional development activities for students returning from cooperative education assignments. Prereq: COOP 002 and EMAE C100.

EMAE 152. Thermodynamics II (3)
Thermodynamic properties of liquids, vapors and real gases, non-reactive mixtures, psychometrics and reactive systems; combustion; thermodynamic cycles. Prereq: ENGR 225.

EMAE 170. Introduction to Mechanical Engineering (3)
Introduces beginning engineering student to how things work through an insightful overview of mechanical and aerospace engineering. Focus is on automobiles, airplanes and flight mechanics, turbomachinery and electric power generation, manufacturing methods, heating and air conditioning, rockets and space flight mechanics. Relevance of math, science and engineering fundamentals to well-founded B.S. engineering programs.

EMAE 172. Mechanical Manufacturing (4)
The course is taught in two sections (Graphics and Manufacturing Processes) through a series of lectures, laboratory sessions and weekly engineering workshop classes. The course aim is to provide a solid manufacturing engineering foundation. The course includes: manual and computer-aided drafting and design (CAD), primary and secondary engineering processes, engineering materials and a field trip to a local company. Laboratory sessions will provide hands-on experience using Pro/ENGINEER CAD software.

EMAE 181. Dynamics (3)
Elements of classical dynamics: particle kinematics and dynamics, including concepts of force, mass, acceleration, work, energy, impulse, momentum. Kinetics of systems of particles and of rigid bodies, including concepts of mass center, momentum, mass moment of inertia, dynamic equilibrium. Elementary vibrations. Prereq: MATH 122 and PHYS 121. ENGR 200 recommended.

EMAE 250. Computers in Mechanical Engineering (3)
Numerical methods including analysis and control of error and its propagation, solutions of systems of linear algebraic equations, solutions of nonlinear algebraic equations, curve fitting, interpolation, and numerical integration and differentiation. Prereq: ENGR 131 and MATH 122.

EMAE 271. Kinematic Analysis and Synthesis (3)
Graphical, analytical, and computer techniques for analyzing displacements, velocities, and accelerations in mechanisms. Analysis and synthesis of linkages, cams, and gears. Laboratory projects include analysis, design, construction, and evaluation of students' mechanisms. Prereq: EMAE 181.

EMAE 282. Mechanical Engineering Laboratory I (2)
Techniques and devices used for experimental work in mechanical engineering and fluid and thermal science. Lectures on topics in the theory of experimentation. Laboratory includes typical experiments, measurements, analysis, and report writing. Prereq: EMAE 181 and ENGR 225.

EMAE 283. Mechanical Engineering Laboratory II (2)
Application of techniques developed in EMAE 282 to solution of individual semester-long experimental projects, including complete report on results. Prereq: EMAE 282.

EMAE 290. Computer-Aided Manufacturing (3)
A manufacturing engineering course covering a wide range of topics associated with the application of computers to the product design and manufacturing process. Topics include: Computer-aided design (CAD) using Pro/ENGINEER software, design methodology, the design/manufacturing interface, introduction to computer numerical control (CNC), manual part-programming for CNC milling and CNC turning machine tools. Significant time will be spent in both CAD and CNC laboratories. Prereq: EMAE 172.

EMAE 325. Fluid and Thermal Engineering II (4)
The continuation of the development of the fundamental fluid and thermal engineering principles introduced in ENGR 225, Introduction to Fluid and Thermal Engineering. Applications to heat engines and refrigeration, chemical equilibrium, mass transport across semi-permeable membranes, mixtures and air conditioning, developing external and internal flows, boundary layer theory, hydrodynamic lubrication, the role of diffusion and convection in heat and mass transfer, radiative heat transfer and heat exchangers. Prereq: ENGR 225.

EMAE 350. Mechanical Engineering Analysis (3)
Methods of problem formulation and application of frequently used mathematical methods in mechanical engineering. Modeling of discrete and continuous systems, solutions of single and multi-degree of freedom problems, boundary value problems, transform techniques, approximation techniques. Prereq: MATH 224.

EMAE 355. Design of Fluid and Thermal Elements (3)
Synthesis of fluid mechanics, thermodynamics, and heat transfer. Practical design problems originating from industrial experience. Prereq: ENGR 225 and EMAE 325.

EMAE 356. Aerospace Design (3)
Interactive and interdisciplinary activities in areas of fluid mechanics, heat transfer, solid mechanics, thermodynamics, and systems analysis approach in design of aerospace vehicles. Projects involve developing (or improving) design of aerospace vehicles of current interest (e.g., hypersonic aircraft) starting from mission requirements to researching developments in relevant areas and using them to obtain conceptual design. Senior standing required.

EMAE 359. Aero/Gas Dynamics (3)
Review of conservation equations. Potential flow. Subsonic airfoil. Finite wing. Isentropic one-dimensional flow. Normal and oblique shock waves. Prandtl-Meyer expansion wave. Supersonic airfoil theory. Prereq: ENGR 225 and EMAE 325.

EMAE 360. Engineering Design (3)
The various elements of design: formulation, conceptualization, selection, and evaluation for the initiation of new designs and the modification of existing designs. Various design methodologies including optimization methods, search techniques, constrained gradient methods, penalty functions, statistical design methods, risk analysis, probabilities of failure, and computer applications. Prereq: ECIV 310.

EMAE 370. Design of Mechanical Elements (3)
Application of mechanics and mechanics of solids in machine design situations. Design of production machinery and consumer products considering fatigue and mechanical behavior. Selection and sizing of basic mechanical components: fasteners, springs, bearings, gears, fluid power elements. Prereq: ECIV 310 and EMAE 271.

EMAE 372. Relation of Materials to Design (4)
The design of mechanical and structural elements considering static failure, elastic stability, residual stresses, stress concentration, impact, fatigue, creep and environmental conditions on the mechanical behavior of engineering materials. Rational approaches to materials selection for new and existing designs of structures. Laboratory experiments coordinated with the classroom lectures. Prereq: ECIV 310.

EMAE 376. Aerostructures (3)
Mechanics of thin-walled aerospace structures. Load analysis. Shear flow due to shear and twisting loads in open and closed cross-sections. Thin-walled pressure vessels. Virtual work and energy principles. Introduction to structural vibrations and finite element methods. Prereq: ECIV 310.

EMAE 378. Mechanics of Machinery I (3)
Comprehensive treatment of design analysis methods and computational tools for machine components. Emphasis is on bearings, seals, gears, hydraulic drives and actuators, with applications to machine tools. Prereq: EMAE 370.

EMAE 379. Mechanics of Machinery II (3)
The focus of this course is Rotating Machinery Vibration, and it is comprised of four major components: 1) modeling, 2) analyses, 3) measurement techniques, and 4) physical insights into rotor vibration phenomena. Prereq: EMAE 181.

EMAE 381. Flight and Orbital Mechanics (3)
Aircraft performance: take-off and landing, unaccelerated flight, range and endurance, flight trajectories, static stability and control, simple maneuvers. Orbital mechanics: the solar system, elements of celestial mechanics, orbit transfer under impulsive thrust, continuous thrust, orbit transfer, decay of orbits due to drag, elements of lift-off and re-entry. Prereq: ENGR 225. EMAE 359 suggested.

EMAE 382. Propulsion (3)
Energy sources of propulsion. Performance criteria. Review of one-dimensional gas dynamics. Introduction of thermochemistry and combustion. Rocket flight performance and rocket staging. Chemical, liquid, and hybrid rockets. Airbreathing engine cycle analysis. Prereq: ENGR 225.

EMAE 387. Vibration Problems in Engineering (4)
Free and forced vibration problems in single and multi-degree of freedom damped and undamped linear systems. Vibration isolation and absorbers. Modal analysis and approximate solutions. Introduction to vibration of continuous media. Noise problems. Laboratory projects to illustrate theoretical concepts and applications. Prereq: MATH 224 and EMAE 181.

EMAE 390. Computer-Integrated Manufacturing (3)
The course is taught through a series of lectures, class discussions, group projects, and laboratory sessions. The course aim is to provide a solid understanding of the many aspects of the engineering processes and systems associated with the integration of product design through to manufacture. Laboratory sessions will provide hands-on experience using a number of Pro/ENGINEER modules to become aware of the integration of manufacturing issues. Prereq: EMAE 290.

EMAE 396. Special Topics in Mechanical and Aerospace Engineering I (1-18)
(Credit as arranged.) Prereq: Consent of instructor.

EMAE 397. Special Topics in Mechanical and Aerospace Engineering II (1-18)
(Credit as arranged.) Prereq: Consent of instructor.

EMAE 398. Senior Project I (3)
Individual or team design or experimental project under faculty supervisor. Prereq: Senior standing, EMAE 360, and consent of instructor.

EMAE 399. Senior Project II (3)
Continuation of EMAE 398.

Graduate Studies

EMAE 400T. Graduate Teaching I (0)
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct contact (for example, teaching recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstrations) and grading activities. The teaching experiences will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Prereq: Ph.D. student in Mechanical Engineering.

EMAE 401. Mechanics of Continuous Media (3)
Vector and tensor calculus. Stress and traction, finite strain and deformation tensors. Kinematics of continuous media, general conservation and balance laws. Material symmetry groups and observer transformation. Constitutive relations with applications to solid and fluid mechanics problems.

EMAE 402. Muscles, Biomechanics, and Control of Movement (4)
Quantitative and qualitative descriptions of the action of muscles in relation to human movement. Introduction to rigid body dynamics and dynamics of multi-link systems using Newtonian and Lagrangian approaches. Muscle models, receptors and reflexes with application to control of multi-joint movement. Forward and inverse dynamics of multi-joint, muscle driven systems. Dissection, observation and recitation in the anatomy laboratory with supplemental lectures concentrating on kinesiology and muscle function. Prereq: EMAE 181 or equivalent. Cross-listed as EBME 402.

EMAE 403. Aerophysics (3)
The course introduces the physical and chemical topics of basic importance in modern fluid mechanics, plasma dynamics, and combustion sciences: statistical calculations of thermodynamic properties of gases; quantum mechanical analysis of atomic and molecular structure; transport phenomena; propagation, emission, and absorption of radiation; chemical and physical equilibria; adiabatic flame temperatures of complex reacting systems; and reaction kinetics.

EMAE 404. Molecular Gasdynamics (3)
This course first discusses the basic kinetic theory model of a gas, including the essential physical ideas and some of the important fundamental results (equilibrium state, entropy, transport coefficients). The major emphasis of the course is on computer simulation methods, especially molecular dynamics and Monte-Carlo methods. A variety of applications is discussed, including basic fluid flows, low earth orbit flight, gas-surface interaction, and nanoscale devices.

EMAE 415. Introduction to Musculo-skeletal Biomechanics (3)
Structural behavior of the musculo-skeletal system. Function of joints, joint loading, and lubrication. Stress-strain properties of bone and connective tissue. Analysis of fracture and repair mechanisms. Viscoplastic modeling of skeletal membranes. Prereq: EMAE 181 and ECIV 310.

EMAE 453. Advanced Fluid Dynamics I (3)
Derivation and discussion of the general equations for conservation of mass, momentum, and energy using tensors. Several exact solutions of the incompressible Newtonian viscous equations. Kinematics and dynamics of inviscid, incompressible flow including free streamline theory developed using vector, complex variable, and numerical techniques.

EMAE 454. Advanced Fluid Dynamics II (3)
Continuation of EMAE 453. Low Reynolds number approximations. Matching techniques: inner and outer expressions. High Reynolds number approximations: boundary layer theory. Elements of gas dynamics: quasi one-dimensional flow, shock waves, supersonic expansion, potential equation, linearized theory, and similarity rules. Prereq: EMAE 453.

EMAE 455. Advanced Thermodynamics (3)
Basic ideas of thermodynamics and dominant methods of their development: operational, postulational, and statistical. Entropy and information theory. Irreversible thermodynamics. Applications.

EMAE 457. Combustion (3)
Chemical kinetics and thermodynamics; governing conservation equations for chemically reacting flows; laminar premixed and diffusion flames; turbulent flames; ignition; extinction and flame stabilization; detonation; liquid droplet and solid particle combustion; flame spread, combustion-generated air pollution; applications of combustion processes to engines, rockets, and fire research.

EMAE 458. Propulsion (3)
Energy sources of propulsion. Momentum theorems and performance criteria. Air breathing systems and their components; chemical rockets—liquid and solid propellant; nuclear rockets—solid core, liquid core and gaseous core; rocket heat transfer and heat protection; electric propulsion—electrothermal, electrostatic and plasma thrustors; thermonuclear propulsion. Prereq: Consent of instructor.

EMAE 459. Advanced Heat Transfer (3)
Analysis of engineering heat transfer from first principles including conduction, convection, radiation, and combined heat and mass transfer. Examples of significance and role of analytic solutions, approximate methods (including integral methods) and numerical methods in the solution of heat transfer problems. Prereq: EMAE 453.

EMAE 460. Theory and Design of Fluid Power Machinery (3)
Fluid mechanic and thermodynamic aspects of the design of fluid power machinery such as axial and radial flow turbomachinery, positive displacement devices and their component characterizations. Prereq: Consent of instructor.

EMAE 471. Design Methods (3)
An advanced course on design methodologies. Conceptualization, preliminary design, detail design, and manufacturing. Failure analysis, materials selection, methods of design optimization, and current approaches in computer-aided design. Prereq: EMAE 360.

EMAE 472. Computers, Optimization, and Design (3)
Application of computer methods to engineering design. Optimization and automated design methods. The use of linear and non-linear programming methods for engineering design and related problems. Unconstrained minimization, penalty functions, feasible directions. Prereq: Consent of instructor.

EMAE 473. Mechanical Behavior of Composite Materials (3)
Mechanical properties, static and dynamic characteristics, stress analysis methods, design properties, manufacturing methods, mechanical testing and design considerations. Prereq: ECIV 310.

EMAE 478. Mechanics of Machinery I (3)
(See EMAE 378.)

EMAE 479. Mechanics of Machinery II (3)
A comprehensive treatment of design analysis methods and computational tools for machine components. Emphasis is on vibration and machinery dynamics.

EMAE 480. Fatigue of Materials (3)
Fundamental and applied aspects of metals, polymers and ceramics. Behavior of materials in stress and strain cycling, methods of computing cyclic stress and strain, cumulative fatigue damage under complex loading. Application of linear elastic fracture mechanics to fatigue crack propagation. Mechanisms of fatigue crack initiation and propagation. Case histories and practical approaches to mitigate fatigue and prolong life.

EMAE 481. Advanced Dynamics I (3)
Particle and rigid-body kinematics and dynamics. Inertia tensor, coordinate transformations and rotating reference frames. Application to rotors and gyroscopes. Theory of orbital motion with application to earth satellites. Impact dynamics. Lagrange equations with applications to multi-degree of freedom systems. Theory of small vibrations. Prereq: EMAE 181.

EMAE 484. Mechanism and Motion Synthesis (3)
Vector methods in planar and three-dimensional mechanisms. Matrix methods and relative spatial motion. Mobility analysis of mechanisms. Body guidance, function, and path generation. Optimal synthesis of mechanisms. Prereq: EMAE 271.

EMAE 486. Stress Waves in Solids (3)
Stress waves in one-dimension, problem formulation for 3-D waves. Reflection and refraction at a plane boundary stress pulses and Raleigh surface waves. Wave guides and dispersion relationships. Solutions of mixed initial and boundary value problems for isotropic linear elastic materials. Scattering of elastic waves. Elastic plastic waves.

EMAE 487. Vibration Problems in Engineering (3)
Free and forced-vibration problems in single and multi-degree of freedom damped and undamped linear systems. Vibration isolation and absorbers. Modal analysis and approximate solutions. Introduction to vibration of continuous media. Noise problems. Laboratory projects to illustrate theoretical concepts and applications. Prereq: EMAE 181 and MATH 224.

EMAE 489. Robotics I (3)
Orientation and configuration coordinate transformations, forward and inverse kinematics and Newton-Euler and Lagrange-Euler dynamic analysis. Planning of manipulator trajectories. Force, position, and hybrid control of robot manipulators. Analytical techniques applied to select industrial robots. Prereq: EMAE 181. Cross-listed as EECS 489.

EMAE 490. World Class Manufacturing (3)
The course is taught through a series of lectures, class discussions, and group projects. The course aim is to provide a solid understanding of the changing technologies and management strategies for companies to maintain competitive advantage in an increasingly global market. Issues such as 'Order Winning Criteria,' 'Lean Manufacturing,' and 'Cellular Manufacturing' will be reviewed and guest speakers will be invited to give an industrial perspective on specific topics of the course. Prereq: EMAE 290, EMAE 390 or permission of instructor.

EMAE 500T. Graduate Teaching II (0)
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct contact (for example, teaching, recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstration) and grading activities. The teaching experience will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Prereq: Ph.D. student in Mechanical Engineering.

EMAE 540. Advanced Dynamics II (3)
Using variational approach, comprehensive development of principle of virtual work, Hamilton's principle and Lagrange equations for holonomic and non-holonomic systems. Hamilton's equations of motion, canonical transformations, Hamilton-Jacobi theory and special theory of relativity in classical mechanics. Modern dynamic system formulations.

EMAE 541. Dynamics of Nonlinear Systems (3)
Nonlinear oscillations; including equations of Duffings, van der Pol, Hill, and Mathieu; and perturbation solution approaches. Bifurcation theory and jump phenomena. Strange attractors, chaos, poincare maps, and related engineering applications.

EMAE 550. Neuromechanics Seminar (0)
(See EBME 550.) Cross-listed as EBME 550.

EMAE 552. Viscous Flow Theory (3)
Compressible boundary layer theory. Blowing and suction effects. Three-dimensional flows; unsteady flows. Introduction to real gas effects. Prereq: EMAE 454.

EMAE 554. Turbulent Fluid Motion (3)
Mathematics and physics of turbulence. Statistical (isotropic, homogeneous turbulence) theories; success and limitations. Experimental and observational (films) evidence. Macrostructures and microturbulence. Other theoretical approaches. Prereq: EMAE 454.

EMAE 556. Variational Methods in Applied Mechanics (3)
Variational and energy principles in dynamics, structures and mechanics of continua. Calculus of variations, principle of virtual work, energy principles and generalization, statics of deformable bodies, dynamics, development of variational principles in fluid mechanics, direct solution methods. Prereq: Consent of instructor.

EMAE 557. Convection Heat Transfer (3)
Energy equation of viscous fluids. Dimensional analysis. Forced convection; heat transfer from non-isothermal and unsteady boundaries, free

convection and combined free and forced convection; stability of free convection flow; thermal instabilities. Real gas effects, combined heat and mass transfer; ablation, condensation, boiling. Prereq: EMAE 453 and EMAE 454.

EMAE 558. Conduction and Radiation (3)
Fundamental law, initial and boundary conditions, basic equations for isotropic and anisotropic media, related physical problems, steady and transient temperature distributions in solid structures. Analytical, graphical, numerical, and experimental methods for constant and variable material properties. Prereq: Consent of instructor.

EMAE 570. Computational Fluid Dynamics (3)
Finite difference, finite element, and spectral techniques for numerical solutions of partial differential equations. Explicit and implicit methods for elliptic, parabolic, hyperbolic, and mixed equations. Unsteady incompressible flow equations in primitive and vorticity/stream function formulations. Steady and unsteady transport (passive scalar) equations. Prereq: Consent of instructor.

EMAE 587. Experimental Stress Analysis (3)
Length, displacement and strain measurements. Electric strain gage, moire, photoelasticity and caustic techniques and their applications to stress analysis. Time and spatially resolved measurements using laser interferometry. Loading devices for studying the mechanical response of engineering materials under static, quasistatic and dynamic loading conditions. Prereq: EMAE 401 or ECIV 411.

EMAE 600T. Graduate Teaching III (0)
This course will engage the Ph.D. candidate in a variety of teaching experiences that will include direct (for example, teaching recitations and laboratories, guest lectures, office hours) as well non-contact preparation (exams, quizzes, demonstrations) and grading activities. The teaching experience will be conducted under the supervision of the faculty member(s) responsible for coordinating student teaching activities. All Ph.D. candidates enrolled in this course sequence will be expected to perform direct contact teaching at some point in the sequence. Prereq: Ph.D. student in Mechanical Engineering.

EMAE 601. Independent Study (1-18)

EMAE 651. Thesis M.S. (1-18)

EMAE 655. Theories of Hydrodynamic Stability (3)
Stability of parallel flows: general development with application to channel flows and boundary layer flows; magnetohydrodynamic parallel flows; rotating Couette flow; superposed fluids; thermal instability of fluids heated from below; non-linear considerations. Prereq: EMAE 454.

EMAE 657. Experimental Techniques in Fluid and Thermal Engineering Sciences (3)
Exposure to experimental problems and techniques provided by the planning, design, execution, and evaluation of an original project. Lectures: review of the measuring techniques for flow, pressure, temperature, etc.; statistical analysis of data: information theory concepts of instrumentation; electrical measurements and sensing devices; and the use of digital computer for data acquisition and reduction. Graduate standing or consent of instructor required.

EMAE 689. Special Topics (1-18)

EMAE 701. Dissertation Ph.D. (1-18)

EMAE 702. Appointed Dissertation Fellow (9)