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Case School of Engineering

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 (<http://engineering.case.edu>) offers thirteen degree programs at the undergraduate level (twelve engineering degrees, plus the BS in computer science). At the post-graduate level, the School of Engineering offers Master of Science programs and the Doctor of Philosophy for advanced, research-based study in engineering. Case School of Engineering 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 Case School of Engineering offers Graduate Certificates which provide an introductory graduate level understanding in the fields of Wireless Health, Wireless Health Product Development, Health Information Technology, Security in Computing, Mobility-Driven Computing and Wearable Computing. The Case School of Engineering also offers two dual-degrees at the graduate level jointly administered with the School of Medicine: a Doctor of Medicine/Master of Science and a Doctor of Medicine/Doctor of Philosophy. 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
- 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 innovation, 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 (1880) and the Case Institute of Technology (1947). The formation of the Case School of Engineering is a re-commitment to the obligations of the gift of Leonard Case, Jr., to serve the citizens of Northern Ohio. The School of Engineering 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.

Accreditation

The following Bachelor of Science programs are accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>):

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Engineering Physics
- Materials Science and Engineering
- Mechanical Engineering
- Polymer Science and Engineering
- Systems and Control Engineering

The following Bachelor of Science program is accredited by the Computing Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>):

- Computer Science

Case School of Engineering's Case Co-op Program is accredited by the Accreditation Council for Cooperative Education (<http://www.coopaccreditation.org/criteria.htm>) (ACCE).

Enrollment Statistics by Degree Program (Fall 2009 through Fall 2013)

CSE Degree Program	Fall 2009	Fall 2010	Fall 2011	Fall 2012	Fall 2013
Aerospace Engineering	67	93	100	102	106
Biomedical Engineering	238	280	311	323	369
Chemical Engineering	123	130	106	92	123
Civil Engineering	56	57	58	48	48
Computer Engineering	65	48	47	41	36
Computer Science (BA and BS)	95	116	143	129	146
Electrical Engineering	70	71	83	91	79
Engineering 1 undesignate	1	0	0	0	0
Engineering 23 Physics	30	22	22	13	15
Materials Science and Engr	20	20	22	23	38
Mechanical Engineering	159	176	187	188	244
Polymer Science and Engr	20	19	31	32	43
Systems and Control Engr	3	6	11	13	12

Graduation Statistics by Degree Program (AY 2009-10 through AY 2013-14)

CSE Degree Program	2009-10	2010-11	2011-12	2012-13	2013-14
Aerospace Engineering	11	32	23	30	31
Biomedical Engineering	88	83	69	92	87
Chemical Engineering	31	52	42	33	34
Civil Engineering	19	19	18	20	13
Computer Engineering	29	24	10	13	19
BA in Computer Science	7	9	14	19	17
BS in Computer Science	19	17	30	26	27

Electrical Engineering	31	27	30	30	38
Engineering 2 (Undesignated)	0	0	0	0	0
Engineering 4 Physics	10	9	4	4	5
Materials Science and Engr	5	4	7	6	7
Mechanical Engineering	45	74	54	62	69
Polymer Science and Engr	8	6	7	10	11
Systems and Control Engr	1	4	3	3	5

Bachelor of Science (p. 4) | Master of Science (p. 4) | Master of Engineering (p. 5) | Master of Engineering and Management (p. 6) | Doctorate (p. 6)

Engineering Degrees Granted

Bachelor of Science in Engineering with the following major field designations:

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Engineering Physics
- Materials Science and Engineering
- Mechanical Engineering
- Polymer Science and Engineering
- Systems and Control Engineering

Bachelor of Science in Engineering (Undesignated) (p. 15) (for programs that emphasize interdisciplinary areas or for programs that include some emphasis on non-technical fields)

Bachelor of Science in Computer Science (p. 56)

Bachelor of Science in Engineering/Master of Science

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computing and Information Science
- Electrical Engineering
- Engineering Physics
- Materials Science and Engineering
- Mechanical Engineering
- Polymer Science and Engineering

- Systems and Control Engineering

Bachelor of Science in Engineering/Master of Engineering

Master of Science with the following major field designations:

- Aerospace Engineering
- Biomedical Engineering, with optional specialization in:
 - Translational Health Technology
 - Wireless Health
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computing and Information Science
- Electrical Engineering, with optional specialization in:
 - Wearable Computing
 - Wireless Health
- Macromolecular Science and Engineering, with optional specialization in:
 - Fire Science and Engineering
- Materials Science and Engineering
- Mechanical Engineering, with optional specialization in:
 - Fire Science and Engineering
- Systems and Control Engineering

Master of Science (Undesignated) (p. 15)

Doctor of Medicine/Master of Science

- Biomedical Engineering

Master of Engineering (practice-oriented program)

Master of Engineering and Management

Doctor of Philosophy with the following major field designations:

- Aerospace Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Computing and Information Science
- Electrical Engineering
- Macromolecular Science
- Materials Science and Engineering
- Mechanical Engineering
- Systems and Control Engineering

Doctor of Medicine/Doctor of Philosophy

- Biomedical Engineering
- Mechanical Engineering

Bachelor of Science in Engineering (p. 4)

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 in the Undergraduate Studies (<http://bulletin.case.edu/undergraduatestudies/csdegree>) section of this bulletin.

Details of the specific curricular requirements for the undergraduate majors are described in the respective departmental descriptions. Details of the requirements of the undesignated engineering undergraduate degree are described under the Engineering Undesignated description.

Master of Science (p. 4)

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 graduate studies.

All Master of Science degree programs require the submission of a Planned Program of Study via the Student Information System where it will be routed for appropriate approvals. Students must submit an approved program of study by the end of the second semester. A revised program of study must be submitted via the Student Information System when any change in the original plan occurs.

Master's Thesis Plan (Plan A)

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.
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, in addition to nine hours of thesis research, must be at the 400 level or higher.

Master's Comprehensive Plan (Plan B)

Students may pursue either a project or non-project track under this option. Minimum requirements for the degree of Master of Science in a major field under this plan are one of the following:

Project track

Completion of 27 hours of graduate course work including three to six hours of Special Problems. Special Problems course work must consist of an engineering project approved by the chair of the department offering the degree, and may be carried out at the student's place of employment with nominal supervision by a faculty advisor or in the school's 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 six hours of Special Problems must be at the 400 level or higher.

Non-project track

Students who register for 27 hours, not including Special Problems course work, must pass satisfactorily a comprehensive examination to be administered by the department or curricular program committee. The examination may be written or oral, or both. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master's Comprehensive Exam before taking the examination.

Distance Education

Through Distance Education, the Case School of Engineering offers graduate courses and degree programs for engineering professionals and students who cannot attend classes on campus. The program makes it convenient for students to overcome the logistical and financial barriers imposed by commuting to campus, and allows students working full time or located a distance from the Cleveland area to pursue a course only (comprehensive option) Master of Science degree (<http://engineering.case.edu/current-students/academic-programs/ms>) or a practice-oriented Master of Engineering degree (<http://engineering.case.edu/meng/>). The courses are delivered asynchronously so that distance learning students can view course lectures at their convenience, and can interact with the professor and students in the class through email, phone, video, and the course tools available in Blackboard. The distance learning courses and degree programs are identical to those given on-campus, and student performance assessments are the same regardless of the delivery mechanism. All distance courses are part of our standard curricula, and are offered on a regular time schedule to allow distance students to complete degree requirements over a predictable and reasonable time period.

For more details on the distance learning programs please visit <http://engineering.case.edu/current-students/distance-learning> and <http://engineering.case.edu/meng/>.

Doctor of Medicine/Master of Science

Medicine is undergoing a transformation based on the rapid advances in science and technology that are combining to produce more accurate diagnoses, more effective treatments with fewer side effects, and improved ability to prevent disease. The goal of the MD/MS in Engineering is to prepare medical graduates to be leaders in the development and clinical deployment of this technology and to partner with others in technology based translational research teams. For further information, see the MD/MS Program in the Biomedical Engineering graduate section of this bulletin (p. 21). Interested students should apply through the biomedical engineering department.

Master of Engineering (p. 5)

The Master of Engineering Program is a graduate degree program that 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 combining core courses that focus on the engineering-business environment and technical elective courses that concentrate on contemporary industrial practice rather than on research.

The Master of Engineering Program prepares students to enhance their role as corporate leaders and 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.

The Master of Engineering Program requires 30 credit hours of course work that include 18 credit hours of core courses and 12 credit hours of technical electives that are chosen from focus areas (see below). It is possible to complete the Master of Engineering degree program within a two-year (six semester), part-time, program of study, although most students choose to complete the program over a seven-nine semester period. The core courses are aimed at equipping participants with knowledge on how engineering is practiced in contemporary industry, and the 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.

Curriculum

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. Up to six transfer credits may be approved for graduate-level courses taken at Case Western Reserve or another accredited university.

Core Courses

EPOM 400	Leadership and Interpersonal Skills	3
EPOM 401	Introduction to Business for Engineers	3
EPOM 403	Product and Process Design and Implementation	3
EPOM 405	Applied Engineering Statistics	3
EPOM 407	Engineering Economics and Financial Analysis	3
EPOM 409	Master of Engineering Capstone Project	3
Total Units		18

Technical Electives

Four courses are chosen from the technical concentration areas below. For detailed course offerings in these areas, please refer to the Master of Engineering (<http://www.engineering.case.edu/meng>) program information on the Case School of Engineering website.

- Biomedical Engineering
- Chemical Engineering
- Computer Engineering
- Infrastructure Engineering
- Macromolecular Science and Engineering
- Materials Processing and Synthesis
- Mechanical Engineering
- Robotics and Control

- Software Engineering
- Signal Processing and Communications

Master of Engineering and Management (p. 6)

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 twenty-eight corporations in the U.S.

The Program

The program includes 42 credit hours of graded course work. The 12-course core sequence makes up 36 of these hours. Students choose an area of concentration, either technology or biomedical, for the remaining six 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.

Twelve Core Courses

IIME 400	Leadership Assessment and Development (LEAD)	3
IIME 405	Project Management	3
IIME 410	Accounting, Finance, and Engineering Economics	3
IIME 415	Materials and Manufacturing Processes	3
IIME 430A	Product and Process Design, Development, and Delivery I	3
IIME 430B	Product and Process Design, Development, and Delivery II	3
IIME 420	Information Technology and Systems	3
IIME 425	Understanding People and Change in Organizations	3
IIME 435	Enterprise Resource Planning in the Supply Chain	3
IIME 440	Six Sigma and Quality Management	3
IIME 450A	Technology Entrepreneurship: Market Opportunity Analysis	3
IIME 450B	Technology Entrepreneurship: Managerial Decision-making	3
Total Units		36

Elective Courses

A total of six credit hours may be chosen from specialized MEM electives listed below or from the Weatherhead School of Management, which are offered by semester. 6

IIME 447	Regulatory Affairs for the Biosciences (*)
IIME 446	Models of Health Care Systems (*)
IIME 470	Independent Projects
IIME 472	BioDesign
IIME 473	Fundamentals of Clinical Information Systems

*The above two courses are 1.5 credit hours and are generally taken together in one semester.

Total Units

6

Doctor of Philosophy (p. 6)

The student's PhD 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 PhD degree before approval of his or her Planned Program of Study via the Student Information System. After this approval has been obtained, it is the responsibility of the student's department to notify the dean 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 BS 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 PhD program of study:
 - i. All 400-, 500-, and 600-level courses
 - ii. Those 300-level courses approved by the student's department up to a maximum of three beyond the BS or a maximum of one beyond the MS
 - iii. 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. All students fulfilling teaching duties must complete UNIV 400A or UNIV 400B.
5. The minimum requirement for research is satisfied by at least 18 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 doctoral 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 MS 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 master's degree, the examination should be taken no later than the end of the third semester at the university.

Planned Program of Study

Each student is required to submit a Planned 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 Planned Program of Study must be submitted via the Student Information System for approval before registering for the last 18 credits hours of the program.

If the student is pursuing the PhD degree without acquiring the MS degree, a petition to waive the requirement of the MS degree should be approved by the departmental advisor and the chair and submitted to the dean of graduate studies. All required courses taken at the university beyond the BS degree should be shown on the Planned Program of Study with the grade if completed. If the requirements are to be fulfilled in ways other than the standard described above, a memorandum requesting approval should be submitted to the dean of graduate studies.

The Planned Program of Study must be submitted within one semester after passing the qualifying examination.

Doctor of Medicine/Doctor of Philosophy

Students with outstanding qualifications may apply to the MD/PhD program. Students interested in obtaining a combined MD/PhD, with an emphasis on basic research in biomedical engineering or mechanical engineering, are strongly encouraged to explore the Medical Scientist Training Program (MSTP), administered by the School of Medicine. For further information, please see the Medical Scientist Training Program (MSTP) in the School of Medicine section of this bulletin. Interested students should apply through the MSTP office in the Medical School.

Graduate Cooperative Education (Co-op)

Graduate Cooperative Education (Co-op) is a formalized academic program that enables students to enhance their classroom studies with career-based experiences in industry. It is a learning experience designed to integrate classroom theory with practical experience and professional development.

Course

ENGR 400C Graduate Cooperative Education, 0 Units.

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.

Graduate Certificates

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings

- **Health Informational Technology**
- **Mobility-Driven Computing**
- **Security in Computing**
- **Wearable Computing**
- **Wireless Health**
- **Wireless Health Product Development**

For more details, please refer to the Graduate Certificate (<http://engineering.case.edu/sandiego/gcademics>) information on the Case School of Engineering - San Diego website.

Interdisciplinary Research Centers

Advanced Manufacturing and Mechanical Reliability Center (p. 7) | Advanced Platform Technology (p. 8) | Case Metal Casting Laboratories (p. 8) | Center for Advanced Polymer Processing (p. 9) | Center for Biomaterials (p. 9) | Center for Dielectrics and Energy Storage (p. 9) | Center for Computational Imaging and Personalized Diagnostics (p. 9) | Center for the Evaluation of Implant Performance (p. 9) | Center for Layered Polymeric Systems (p. 10) | Center for Modeling Integrated Metabolic Systems (p. 10) | Cleveland Functional Electrical Simulation Center (p. 10) | Control and Energy Systems Center (p. 10) | Electronics Design Center (p. 11) | Great Lakes Energy Institute (p. 11) | Institute for Advanced Materials (p. 11) | Microfabrication Laboratory (p. 12) | National Center for Space Exploration Research (p. 12) | Neural Engineering Center (p. 12) | Nitinol Commercialization Accelerator (p. 12) | Solar Durability and Lifetime Extension (p. 13) | Swagelok Center for Surface Analysis of Materials (p. 13) | Wind Energy and Research and Commercialization Center (p. 13)

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 Manufacturing and Mechanical Reliability Center (AMMRC (<http://ammrc.case.edu>)) (<http://ammrc.case.edu>)

White Building (7205)
Phone: 216.368.4234
John J. Lewandowski, Director
john.lewandowski@case.edu

The Advanced Manufacturing and Mechanical Reliability Center (AMMRC) was established to provide advanced manufacturing (e.g.

deformation processing, extrusion, forming, etc.) and mechanical characterization (e.g. mechanical testing, reliability testing, fatigue, etc.) expertise to the CWRU campus, medical, industrial, legal, outside university, and government laboratory communities. The center, housed in the Charles M. White Metallurgy building, currently maintains equipment valued in excess of \$4.5M and has been accessed by the local, national, and international communities. The CWRU campus community can access the facility via the use of a valid CWRU university account number that will be charged at an internal rate for machine time, including set up and any technician time involved. Long term testing can be provided at pro-rated charges in consultation with the center directors. Arrangements can be made to train users on the equipment and reserve time for equipment use by contacting the center co-director. Outside (i.e. non-CWRU) users can access the facility via a number of different mechanisms by contacting the center director.

In general, the center is capable of mechanically evaluating and deformation processing materials that range in size scale from the micrometer range up through bulk quantities. This unique facility enables mechanical characterization at loading rates as low as one micrometer/hour (i.e. rate of fingernail growth!) up through impact (e.g. 3-4 meters/sec) at temperatures ranging from -196C (i.e. liquid nitrogen) up to 1400C. Hot microhardness testing up to 1000C is available. Monotonic as well as cyclic fatigue testing is possible in addition to evaluations of mechanical behavior and processing with superimposed pressures up to 2 GPa. Novel high-rate and multiple-deformation sequence forging simulations are possible with the use of a multi-actuator forging simulator, in addition to sheet metal forming experimentation with independent control of forming rate and blank hold down force. Hot extrusion is also possible at temperatures up to 900C on 0.5" diameter billets. Materials systems that have been investigated span the range of organic and inorganic materials, including metals, ceramics, polymers, composites, electronic materials, and biomedical materials systems. Descriptions of specific equipment and capabilities are provided with the website link.

Advanced Platform Technology (APT) Center (<http://www.aptcenr.research.va.gov>)

Louis Stokes Cleveland Department of Veterans Affairs Medical Center
10701 East Boulevard, Mail Stop 151 AW/APT
Cleveland, Ohio 44106
Phone: 216.707.6421 Fax: 216.707.6420
Ronald J. Triolo, Executive Director
ronald.triolo@case.edu (//ronald.triolo@case.edu)

The Advanced Platform Technology (APT) Center brings together top faculty and researchers from Case Western Reserve University and the Department of Veterans Affairs to capture the most recent developments in the fields of **microelectronics, material science, microsystems** and **mechanics**, and focus them on the practical medical needs of individuals disabled by sensorimotor dysfunction, cognitive deficits or limb loss. The APT Center creates novel, cross-cutting technologies for the diagnosis, treatment or study of high priority clinical conditions within a structured framework that facilitates regulatory compliance, outsourcing by contract manufacturers, and dissemination within the rehabilitation community. Scientific technical development and clinical translation concentrates on **prosthetics and orthotics, health monitoring and maintenance, neural interfaces** and emerging **enabling technologies**. Center projects to date have concentrated primarily on developing new materials and microsystems for interfacing with the nervous system, repairing orthopaedic trauma and accelerating wound healing, replacing or restoring natural limb, sensory and organ system function, and both monitoring and promoting neurological, genito-urinary and vascular

health. The APT Center was established as a VA Center of Excellence in 2005 in partnership with Case Western Reserve University and is based at the Louis Stokes Cleveland Department of Veterans Affairs Medical Center (LSCDVAMC). The center is able to provide or facilitate access to the following resources:

1. Neural modeling and analysis of interface designs
2. Polymer and bioactive material development
3. Microelectromechanical (MEMS) systems design and fabrication
4. Rapid prototyping, mechanical testing and dynamic simulation
5. Pre-clinical *in vitro* and *in vivo* verification of device performance
6. Circuit and software design and fabrication
7. System validation and design control documentation
8. Professional engineering support and project management
9. Administrative support for intellectual property protection and regulatory affairs

Case Metal Casting Laboratories (CMCL) (<http://engineering.case.edu/groups/CMPL>)

113 White Bldg.
David Schwam, Director
david.schwam@case.edu (dxs11@case.edu)

The CMCL houses state-of-the-art, melting and casting capabilities for a wide range of ferrous and non-ferrous alloys. The facility is a unique combination of laboratory and industrial scale equipment. Research projects with federal and industrial support are carried out by teams of faculty, graduate and undergraduate students. Manufacturing of castings are from Computer Aided Design, flow and solidification simulation, rapid prototyping, molding to melting and casting. Provides hands-on experiential learning opportunities for engineering students in laboratory classes and summer research programs.

- Industrial UBE 350 Ton Vertical Squeeze casting machine for casting high integrity parts
- 350kW/1000MHz Inductotherm solid-state melting power supply with furnaces up to 1,500 lb. steel
- 50 lb. vacuum melting and casting furnace driven by a new 35kW/10kHz Inductotherm power supply
- Sand molding and sand testing equipment
- Permanent molds for casting test bars and evaluation of molten metal quality
- Foseco rotary degasser for non-ferrous alloys
- Lindberg 75 kW electrical melting furnace for 800 lb. of aluminum
- Denison four post, hydraulic 50 ton rapid acting squeeze caster
- Squeeze casting tooling with preheatable dies
- Equipment for melting and casting magnesium alloys
- Computer modeling workstations with flow and heat transfer finite element software
- Thermal Fatigue Testing Units for cyclical immersion in molten aluminum (Dunkers)
- 3-D Printer for Rapid Prototyping
- 100W Nd:YAG laser
- Thermal Technologies arc melting unit
- Centorr vacuum heat treating furnace

Center for Advanced Polymer Processing (CAPP) (<http://engineering.case.edu/centers/capp>)

Kent Hale Smith Building, 3rd floor
 Phone: 216.368.6372 Fax 216.543.4202
 Joao Maia, Director
joao.maia@case.edu

CAPP is a state-of-the-art center for advanced polymer blending and compounding and reactive extrusion at CWRU able to perform basic research and applied research and development in support of the Ohio and US plastics industry. The main tools of CAPP are:

- State-of-the-art sensors that allow multiple rheological, physical, chemical and morphological quantities to be measured along the screw axis of twin-screw extruders;
- Advanced multi-scale computational simulation capabilities to build physical-chemical-structural models of polymer systems under flow in realistic polymer transformation processes;
- Integration of on-line sensors and multi-scale softwares to develop new advanced and functional multiphase complex materials or optimize the performance of existing ones.

Center for Biomaterials (p. 9)

202 Wickenden Building (7207)
 William Marx, Interim Director
william.marx@case.edu

Anirban Sen Gupta, Associate Director
 Phone: 216.368.4564
anirban.sengupta@case.edu (//anirban.sengupta@case.edu)

The Center for Biomaterials carries out research and development projects to investigate new biomaterials, tissue engineered materials, and targeted drug delivery systems for use in cardiovascular applications and implants. The Center for Biomaterials also provides researchers access to shared use facilities, which includes high resolution microscopy such as AFM, molecular spectroscopies, surface analysis, and polymer and peptide synthesis capabilities. The chemical and mechanical interface between the biomaterial and the host tissue 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; and cardiovascular and neural tissue engineering based on biomimetic designs. Studies at the cell and molecular level assist our understanding of the underlying mechanisms so that novel biomedical materials may be designed, prepared, and characterized.

Center for Computational Imaging and Personalized Diagnostics (CCIPD) (<http://engineering.case.edu/centers/ccipd>)

Wickenden Building Room 515
 Phone: 216.368.5891
 Anant Madabhushi, Director
anant.madabhushi@case.edu

The Center of Computational Imaging and Personalized Diagnostics at Case Western Reserve University is involved in various different

aspects of developing, evaluating and applying novel quantitative image analysis, computer vision, signal processing, segmentation, multi-modal co-registration tools, pattern recognition, and machine learning tools for disease diagnosis, prognosis, and theragnosis in the context of breast, prostate, head and neck, and brain tumors as also epilepsy and carotid plaque. Our group is also exploring the utility of these methods in studying correlations of disease markers across multiple scales, modalities, and functionalities - from gene and protein expression to spectroscopy to digital pathology and to multi-parametric MRI.

Center for Dielectrics and Energy Storage (CDES) (p. 9)

312 Kent Hale Smith Building
 Phone: 216.368.5861
 Lei Zhu, Director
lxz121@case.edu

CDES mission is to discover, develop, and translate novel dielectric technologies for energy storage and capacitor applications. Researching high energy density, high temperature, and low loss dielectric film capacitors, we integrate these innovations with storage devices, hybrid electric vehicles, multi-megawatt power conditioning, pulsed power, and high energy physics applications. Originating from the Center for Layered Polymeric Systems (CLiPS), a National Science Foundation Science and Technology Center focusing on research, innovation, and education through a unique multilayer film technology, CDES extends this technology into new energy frontiers.

CDES has access to state-of-the-art equipment, which includes process equipment for fabricating, stretching, and testing dielectric films, including:

- Novocontrol Concept 80 Broadband Dielectrics Spectrometer
- Radiant Premier II Ferroelectric Tester
- Bruckner Kato IV Biaxial Stretcher

In addition to research, CDES plays a significant role in educating undergraduate students, graduate students, and post-doctoral associates to work in advanced energy material fields.

Center for the Evaluation of Implant Performance (<http://engineering.case.edu/centers/implantperformance>)

Wearn Building Room 511
 Phone: 216.844.1745
 Clare Rimnac, Director
clare.rimnac@case.edu

The mission of the Center for the Evaluation of Implant Performance is to pursue engineering and scientific analysis of retrieved joint reconstruction devices and to evaluate the performance of implants during patient use. This mission is achieved through IRB-approved collection, maintenance, and protection of clinical and radiographic information and total joint replacement components obtained at revision or removal surgery. The goal is to advance the science of joint replacement durability and improved performance for better patient outcomes through improvements in implant materials and design. To this end, the Center for the Evaluation of Implant Performance works in partnership with the Center for Joint Replacement and Restoration at University Hospitals Case Medical Center.

Center for Layered Polymeric Systems (CLiPS) (<http://www.stc-clips.org>)

NSF Science and Technology Center
420 Kent Hale Smith Building (7202)
Phone: 216.368.4203 Fax 216.368.6329
Eric Baer, Director
eric.baer@case.edu

CLiPS researchers and educators work together to accomplish the Center's mission of advancing the nation's science and technology agenda through development of new materials systems and for educating a diverse American workforce through interdisciplinary education programs.

CLiPS research focuses on exploration of multilayered polymeric systems at the micro- and nano-layer levels and has revealed unique properties and capabilities that are different, and often not predicted, from systems involving the same materials on a larger scale. Technology refined within CLiPS allows the production of films and membranes composed of hundreds or thousands of layers. These extremely thin layers promote interactions approaching the molecular level between the materials used in the process.

The research activities are organized into five platforms to exploit the microlayer and nanolayer structures: (1) **Rheology and New Processing** focuses on integrating rheology into the multilayering process, and will explore combinations of rheologically dissimilar materials to create new polymer-based structures; (2) advanced **Membranes and Transport Phenomena** that exploit the layered hierarchy to achieve unique transport properties; (3) novel **Optic and Electronic Systems** based on the advanced layered materials; (4) **Science and Technology Initiatives** that probe a fundamental understanding and explore new opportunities for the layered structures; and (5) **Templated Interfaces and Reactions** looking at polymer materials that are amenable to patterning and ordering, and exhibit a specific field response. Of particular interest are polymer systems and nanomaterials that are appropriate for biological applications.

CLiPS was established in 2006 with funding by the National Science Foundation as a Science and Technology Center. It is the first NSF STC ever to be established at Case Western Reserve University. CLiPS is a national center involving close partnership with the University of Texas, Fisk University, the University of Southern Mississippi, and the Naval Research Laboratory, and an important educational partnership with the Cleveland Metropolitan School District.

Center for Modeling Integrated Metabolic Systems (MIMS) (<http://casemed.case.edu/mims>)

410 Wickenden (7207)
Phone: 216.368.4066 Fax: 216.368.4969
Gerald M. Saidel, Director
gerald.saidel@case.edu (//gms3@case.edu)

The primary aim of the MIMS Center is to develop mechanistic, mathematical models to simulate cellular metabolism in various tissues and organs (i.e., skeletal muscle, heart, brain, and adipose tissue) and to integrate these components in whole-body models. These biologically and physiologically based computational models incorporate cellular metabolic reactions and transport processes of a large number of chemical species. Model parameters quantitatively characterize metabolic

pathways and regulatory mechanisms under normal and abnormal conditions including obesity and hypoxia as well as in disease states including type-2 diabetes, cystic fibrosis, and chronic kidney disease. The large-scale, complex mathematical models are solved numerically using sophisticated computational algorithms to simulate and analyze experimental responses to physiological and metabolic changes. Model parameters are optimally estimated by minimizing differences between model simulated outputs and experimental data using large-scale, nonlinear optimization algorithms. Experimentally validated models are used to predict the effects of altering metabolic processes with disease states, pharmacological agents, diet, and physical training.

Cleveland Functional Electrical Stimulation Center (FES) (<http://fescenter.org>)

11000 Cedar Avenue, Suite 230
Phone: 216.231.3257 Fax: 216.231.3258
Robert J. Kirsch, Director
<mailto://info@FEScenter.org> (//info@FEScenter.org)

Functional electrical stimulation (FES) is the application of electrical currents to either generate or suppress activity in the nervous system. FES can produce and control the movement of otherwise paralyzed limbs, for standing and hand grasp; activate visceral bodily functions, such as micturition; create perceptions such as skin sensibility; arrest undesired activity, such as pain or spasm; and facilitate natural recovery and accelerate motor relearning. FES is particularly powerful and clinically relevant, since many people with neurological disabilities retain the capacity for neural conduction, and are thus amenable to this intervention.

The center focuses its activities in four major areas:

- Fundamental studies to discover new knowledge
- Enabling technologies for clinical application or the discovery of knowledge
- Clinical research that applies this knowledge and technology to individuals with neurological dysfunction
- Transfer of knowledge and technology to the clinical community and to industry.

The FES Center was established as a VA RR&D Center of Excellence in 1991 and is based at the Louis Stokes Cleveland VAMC (CVAMC). The center is a consortium with three institutional partners: CVAMC, Case Western Reserve University (CWRU), and the MetroHealth Medical Center (MHMC). The center accomplishes its mission by integrating and facilitating the efforts of scientists, engineers, and clinicians through common goals and directions in the major clinical areas, and by providing mechanisms to accomplish these goals across the institutional partners.

Control and Energy Systems Center (CESC) (<http://cesc.case.edu>)

Olin Building, 6th Floor
Phone: 216.368.5122
Mario Garcia-Sanz, Director
mario@case.edu

The Control and Energy Systems Center (CESC) looks for new transformational research and engineering breakthroughs to build a better world, improving our industry, economy, energy, environment, water resources and society, all with sustainability and within an international collaboration framework. With an interdisciplinary and

concurrent engineering approach, the Control and Energy Systems Center focuses on bridging the gap between fundamental and applied research in advanced control and systems engineering, with special emphasis in energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research is conducted to gain knowledge and understanding on multi-input-multi-output physical worlds, nonlinear plants, distributed parameter systems, plants with non-minimum phase, time delay and/or uncertainty, etc., and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems. Applied research helps develop advanced solutions with industrial partners, for practical control engineering problems in Energy Systems, Multi-megawatt Wind Turbines, Renewable Energy Plants, Power System Dynamics and Control, Grid Integration, Energy Storage, Power Electronics, Wastewater Treatment Plants, Desalination Systems, Formation Flying Spacecraft, Satellites with Flexible Appendages, Heating Systems, Robotics, Parallel Kinematics, Telescope Control, etc.

Electronics Design Center (EDC) (<http://engineering.case.edu/edc>)

112 Bingham (7200)
Phone: 216.368.2935 Fax: 216.368.8738
Chung-Chiun Liu, Director
chung-chiun.liu@case.edu

The Electronics Design Center (EDC) is a multi-disciplinary educational and research center focusing on the applications of microfabrication processing to the advancement of chemical and biological micro-systems specializing in application-oriented electrochemical based biosensors. The center has complete thick film and thin film processing facilities, including screen printing, ink jet printing and sputtering equipment. Other facilities supporting the microfabrication processing are also readily available. The EDC is a resource for industrial and academic researchers, offering access to equipment, laboratories and trained staff.

Great Lakes Energy Institute (GLEI) (<http://energy.case.edu>)

305 Olin Building (7074)
Phone: 216.368.0748
Dianne Anderson, Executive Director
dianne.anderson@case.edu

The Great Lakes Energy Institute empowers our faculty, students and partners to catalyze breakthroughs in energy sustainability that address the most pressing problems facing our world. Since 2008, GLEI has helped catalyze a four-fold increase in energy research, won awards from NSF, DOE, ARPA-E, Ohio Third Frontier and other organizations, attracted nearly \$10 million in gifts, worked with over 100 different industry partners, and encouraged multidisciplinary proposals throughout the university. GLEI is in the top five leading Department of Energy ARPA-E awards. At the heart of these efforts are over 100 engaged faculty, hailing from engineering, arts & sciences, management, and law. And while GLEI's work supports all types of energy, their focus lies in five priority areas:

Future Grid - CWRU's energy program is underpinned by research in power systems. Strengths in controls, sensors, and electronics provide a core foundation for smart grid connectivity of energy and storage.

Wind Energy - Wind energy emphasizes offshore deployment and is founded on wind and ice measurement, controls, power management,

and grid interface expertise. Much of this work is supported by DOE awards and the State of Ohio.

Solar - Research in next generation photovoltaics (PV) focuses on organics and lifetime and degradation science, stemming from a strong reputation in materials, research, and development.

Storage - Storage research builds on historical strengths in electrochemistry, materials and lifetime and degradation science. Recent research awards include ARPA-E and DOE.

Shale Energy - Research focuses on technologies that enhance safe extraction, transport and processing of shale gas and oil in Ohio. Strengths are present in macromolecules, sensors, corrosion-resistant casings, cementitious materials, and modeling and simulation of hydro-fracking process.

The role of CWRU in energy also touches economic development and education. Through research and investment, university spin-outs are poised to contribute to a new energy economy while working toward a clean and sustainable future. Students undertake key roles in the research and commercialization of the energy technologies underpinning this transition and contribute to worldwide impact.

Institute for Advanced Materials (<http://engineering.case.edu/centers/IAM>)

519 Kent Hale Smith Building
Phone 216.368.4242
Stuart Rowan, Director
stuart.rowan@case.edu

The Institute for Advanced Materials is a clearinghouse for Case Western Reserve's materials research and provides access to the university's world-class expertise and state-of-the-art facilities. One of Ohio's Centers of Excellence in Enabling Technologies: Advanced Materials and Sensors, the institute matches industry and governmental partners with campus-based collaborators to explore solutions to real world problems.

Advanced materials—polymers, metals, ceramics, composites, and biomaterials— are cornerstones to many emerging technologies like biocompatible medical implants, energy storage, and environmentally sustainable consumer products. Recognizing that, in Ohio, approximately ten percent of the state's high tech workforce is engaged in advanced materials and related area industries, the Institute for Advanced Materials at Case Western Reserve aims to leverage and enhance Ohio's industrial base and manufacturing capabilities, impact the global materials community, educate future materials leaders, and serve as a single, unified resource for advanced materials research.

Approximately 100 faculty, including several members of the National Academies, spanning four schools—Engineering, Arts & Sciences, Medicine and Dental Medicine—work with industrial partners and institutional collaborators to generate \$38 million of annual materials research income with support from the National Institute of Health, the National Science Foundation, the US Department of Energy and the Department of Defense among others.

By harnessing the breadth of Case's research base and creating new collaborative teams, the Institute for Advanced Materials drives the integration of new materials innovations from initial ideas to marketable technologies in energy, sustainability and human health.

Microfabrication Laboratory (MFL) (<http://mems.case.edu>)

342 Bingham Building (7200)
Phone: 216.368.6117 Fax: 216.368.6888
Christian Zorman, Director
christian.zorman@case.edu

MFL houses a state-of-the-art facility that provides the latest in microfabrication and micromachining processes. The laboratory focuses on the applications of microfabrication and micromachining technology to a wide range of sensors, actuators and other microelectromechanical (MEMS) systems. In addition to silicon based technology, the laboratory has a unique strength in silicon carbide micromachining that is particularly valuable for applications in harsh environments. To support the development of flexible microsystems, polymer micromachining is also available. Undergraduate students, graduate students, and post-doctoral assistants use the laboratory's facilities to carry out their research or special projects.

Researchers not affiliated with CWRU can also use the laboratory through a facilities use agreement.

National Center for Space Exploration Research (NCSER) (<http://engineering.case.edu/emaef/index.php?q=Facilities/NCSER>)

21000 Brookpark Rd., MS 110-3
Phone: 216.433.5031
Mohammad Kassemi, Chief Scientist
mohammad.kassemi@nasa.gov

The National Center for Space Exploration Research (NCSER) is a collaborative effort between the Universities Space Research Association (USRA), Case Western Reserve University (CWRU), and NASA Glenn Research Center (GRC) that provides GRC with specialized research and technology development capabilities essential to sustaining its leadership role in NASA missions. Expertise resident at NCSER includes reduced gravity fluid mechanics, reduced gravity combustion processes; heat transfer, two-phase flow, micro-fluidics, and phase change processes; computational multiphase fluid dynamics, heat and mass transfer, computational simulation of physico-chemical fluid processes and human physiological systems. This expertise has been applied to:

- Cryogenic fluid management
- On orbit repair of electronics
- Spacecraft fire safety
- Exploration life support
- Energy storage
- Dust management
- Thermal management and control
- Environmental monitoring/control
- ISS experiment development Integrated system health monitoring
- Astronaut health
- Planetary Surface Mobility
- In situ resource utilization
- Materials synthesis
- Bio-fluid mechanics
- Biosystems modeling

- Fluid-Structural-Interaction and tissue mechanics in physiological systems.

Neural Engineering Center (NEC) (<http://nec.case.edu>)

112 Wickenden (7207)
Phone: 216.368.3974 Fax: 216.368.4872
Dominique Durand, Director
dominique.durand@case.edu (//dxd6@case.edu)

The research mission of the center is to bring to bear combined tools in physics, mathematics, chemistry, engineering and neuroscience to analyze the mechanisms underlying neuronal function and to solve the clinical problems associated with neuronal dysfunction. Research areas include: Neuromodulation, Neuroprostheses, Quantitative Neurophysiology, Neural Dynamics, Neuro-Mechanical Systems, Neural Regeneration, Neural Interfacing, Neural Imaging and Molecular Sensing, Neuro-Magnetism, and Systems Neuroscience. The education mission of the center is to provide engineers and scientists with an integrated knowledge of engineering and neuroscience capable of solving problems in neuroscience ranging from the molecules to the clinic. The center is also an outlet for technology transfer of new ideas to be commercialized by industrial partners. The center's goals are accomplished by fostering interdisciplinary research between clinicians, scientists, students and local industry, educational experiences including didactic material, laboratory experience and clinical exposure, and close ties to industrial partners.

Nitinol Commercialization Accelerator (NCA) (<http://ammrc.case.edu/node/50>)

White Building (7205)
Phone: 216.368.4234
John J. Lewandowski, Director
john.lewandowski@case.edu
James D. McGuffin-Cawley, Co-Director
David Schwam, Co-Director

The Ohio Third Frontier Wright Projects Program has funded the Nitinol Commercialization Accelerator (NCA), a collaborative effort between the Cleveland Clinic, CWRU, University of Toledo, NASA Glenn Research Center, and Norman Noble, Inc. in order to develop a better understanding of the metallurgical processing and mechanical characterization of nitinol for use in biomedical and aerospace applications. Biomedical applications range from orthodontia to implantable devices while higher temperature shape memory alloys are of interest for aerospace. The collaboration is designed to create synergy amongst collaborators in the research and development of nitinol products.

The laboratory housed at CWRU's Material Science and Engineering Department contains processing and characterization (thermal and mechanical) equipment that allows for the manufacture and analysis of nitinol products. Processing equipment includes a vacuum arc casting unit, vacuum heat treatment system, and hot extrusion capabilities. Thermal characterization equipment includes a high temperature Differential Scanning Calorimeter (DSC) while mechanical characterization equipment for testing wire/foil includes a number of flex bending fatigue machines, rotary bending fatigue machines, and tabletop tension testing machines.

The Cleveland Clinic and NASA Glenn Research Center also house equipment associated with the NCA program including: Raydiance-

Rofin Femtosecond Laser, Techne FB-08 Precision Calibration Bath, MTS Cryo-chamber and Grips, and an Aramis/Optotrak Certus 3D Strain Mapping system.

Solar Durability and Lifetime Extension (SDLE) Center (<http://engineering.case.edu/centers/sdle>)

Labs: White Building, 5th Floor / Sun Farm: CWRU West Campus
Phone: 216.368.3655/216.368.0374
Roger H. French, Director
roger.french@case.edu

Christopher Littman, Program Manager
christopher.littman@case.edu

The SDLE Center was established in 2011 with funding from Ohio Third Frontier, and is dedicated to advancing the field of lifetime and degradation science. Activities in the Center focus on durability and degradation of environmentally exposed, long lived materials and technologies such as photovoltaics (PV), energy efficient lighting, and building envelope applications. The Center develops real-time and accelerated protocols for exposure to solar radiation and related environmental stressors to enable the evaluation of the environmental durability and lifetime of materials, components, and products. Researchers perform post-exposure optical and thermo-mechanical measurements to develop quantitative mechanistic models of degradation processes. The SDLE Center's capabilities and equipment include:

- Outdoor solar exposures: SunFarm with 14 dual-axis solar trackers with multi-sun concentrators, and power degradation monitoring
- Solar simulators for 1-1000X solar exposures
- Multi-factor environmental test chambers with temperature, humidity, freeze/thaw, and cycling
- A full suite of optical, interfacial, thermo-mechanical and electrical evaluation tools for materials, components and systems

Swagelok Center for Surface Analysis of Materials (SCSAM) (<http://engineering.case.edu/centers/scsam>)

110 Glennan Building
Phone: 216.368.3868
A. H. Heuer, Director
arthur.heuer@case.edu

F (ahh@case.edu) Frank Ernst, Co-Director
frank.ernst@case.edu (fxe5@case.edu)

Mohan Sankaran, Co-Director
mohan@case.edu

The SCSAM (Swagelok Center for Surface Analysis of Materials) is a multi-user analytical facility providing instrumentation for microstructural characterization and surface and near-surface chemical analysis. SCSAM's 16 major instruments encompass a wide range of characterization techniques, providing a uniquely comprehensive resource for cutting-edge microcharacterization of materials. The facility is staffed by six full-time engineers who maintain the instrumentation and assist users in acquiring useful data.

Current capabilities include the following: (i) 4 scanning electron microscopes with additional capabilities for FIB (focused ion beam) micromachining, XEDS (X-ray energy-dispersive spectrometry), and EBSP (electron backscattering patterns). (ii) 2 transmission electron microscopes capable of STEM (scanning transmission electron microscopy) and equipped with XEDS systems and imaging energy filters enabling EFTEM (energy-filtering TEM) techniques and EELS (electron energy-loss spectrometry). (iii) Two scanning probe microscopy systems, one a standard atomic-force microscope with an attachment for nanotribology (Hysitron Triboscope), the other a variable-temperature UHV (ultra-high vacuum) atomic-resolution instrument for STM (scanning tunneling microscopy), STS (scanning tunneling spectroscopy), and all modes of AFM. (iv) A laser scanning confocal microscope dedicated for materials studies, including Raman microscopy. (v) An automated Nanoindenter. (vi) 3 X-ray diffractometers. (vii) A ToF-SIMS (time-of-flight secondary-ion mass spectrometer). (viii) A SAM (scanning Auger microprobe) which provides high spatial resolution surface microanalysis, as well as depth profiling. (ix) An XPS (X-ray photoelectron spectrometer, also known as ESCA (electron spectrometer for chemical analysis)) operating with a small probe size X-ray beam, and allowing efficient concentration-depth profiling.

SCSAM is administratively housed in the Case School of Engineering (CSE) and is central to much of the research carried out by the seven departments within CSE. However, the facility is extensively used by the Physics, Chemistry, Biology and Earth, Environmental, and Planetary Sciences departments within the College of Arts and Sciences, and by many departments within the Schools of Medicine and Dental Medicine. In addition to CWRU clients, many external institutions utilize SCSAM's facilities, including NASA Glenn Research Center, the Cleveland Clinic, and numerous Ohio universities. More than 250 users utilize the facility in any given year.

SCSAM's instruments are housed in a centralized area, allowing users convenient access to state-of-the-art solutions for their analytical needs.

Wind Energy Research and Commercialization (WERC) Center (<http://energy.case.edu/WERC-Center>)

307 Olin Building
Great Lakes Energy Institute
Phone: 216.368.1366, Fax: 216.368.3209
David H. Matthiesen, Director
david.matthiesen@case.edu (David.Matthiesen@case.edu)

The WERC Center is a multidisciplinary center for use by students, faculty, and industry providing instrumentation for wind resource characterization and research platforms in operating wind turbines. The WERC Center was established in 2010 with funding from the Ohio Department of Development Third Frontier Wright Project and the Department of Energy. Additional support was provided by the following inaugural industrial partners: Cleveland Electric Laboratories, The Lubrizol Corporation, Parker Hannifin Corporation, Azure Energy LLC., Rockwell Automation, Inc., Swiger Coil Systems LLC., and Wm. Sopko & Sons Co.

The instruments in the WERC Center include:

- A continuous scan ZephIR LiDAR, manufactured by Natural Power. This instrument measures horizontal and vertical wind velocity along with wind direction at 15 second intervals at five user set heights up to 200 m.

- Five meteorological measurement systems: 3 on campus; 1 with the off-campus wind turbines; and one at the City of Cleveland's water intake crib located 3.5 miles offshore in Lake Erie.
- An ice thickness sensor that is deployed at the bottom of Lake Erie each fall and retrieved in the spring.
- A NorthWind 100 wind turbine manufactured by Northern Power Systems in Barre, Vermont, USA. This 100kW community scale wind turbine has a direct drive generator with full power inverters, stall control blades with a 21 m rotor diameter, and a 37 m hub height. This wind turbine is located on campus just east of Van Horn field and began operation in November, 2010.
- A Vestas V-27 wind turbine originally manufactured by Vestas in Denmark. This 225kW medium scale wind turbine has a gearbox drive generator, pitch controlled blades with a 27 m rotor diameter, and a 30 m hub height. In addition it has a 50kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in March, 2012.
- A Nordex N-54 wind turbine originally manufactured by Nordex in Germany. This 1.0MW utility scale wind turbine has a gearbox drive generator, stall control blades with a 54 m rotor diameter, and a 70 m hub height. In addition it has a 200kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in October, 2012.

Educational Facilities

Nord Computer Laboratory (<http://engineering.case.edu/about/facilities/nord-computer-lab>)

This is a general purpose computer facility, provided by the Case School of Engineering, open 24 hours a day, available to all CWRU students. The lab contains 56 Thin Clients running Windows 7 Enterprise. Software includes MS Office, Adobe Suite, MATLAB, SolidWorks, ChemBioDraw, CES EduPack, and many others. Facilities for color printing, faxing, copying and scanning are provided.

think[box] (<http://engineering.case.edu/thinkbox>)

Case Western Reserve University's new invention center provides a space for anyone - especially students, faculty, and alumni - to tinker and creatively invent. Housed temporarily in a 4,500 square foot space, this project will be moving into a 7-story, 50,000 square foot facility, making it one of the largest university invention centers in the world.

About think[box]

Think[box] is creating a distinct, on-campus environment where hands-on education, design and development, and product commercialization can all take place, and where these activities can interact and cross fertilize. More than a meeting place or world-class fabrication laboratory, it is home to educators, advisors, mentors, and facilitators who can assist students and faculty into becoming tomorrow's entrepreneurs and technology leaders.

Vision

The vision of think[box] is to change the economic and social culture of the university and region by emphasizing cross-discipline and cross-institution collaborative endeavors that push creativity and innovation to

their limits. Think[box] will provide a project-based learning environment where students from all courses of study have an opportunity to understand how innovation and creativity can lead to economic and social advancement. This exposure will encourage entrepreneurial thinking among our students, who will then be poised to become the leaders and innovators of the future. Simultaneously, think[box] will create an entrepreneurial environment where these ideas can be nurtured, developed, funded, and commercialized.

Mission

The mission of think[box] is to establish, on campus, a physical and cultural focal point that will:

- Provide an educational environment that fosters collaboration, creativity, and invention.
- Provide comprehensive resources for innovation and value creation.
- Create an engine for entrepreneurial growth within our community by identifying and nurturing the talents and expertise of CWRU students, faculty, and staff, as well as those of the surrounding community.

Administration

Jeffrey L. Duerk, PhD
(Case Western Reserve University)
Dean of the Case School of Engineering and Leonard Case Professor

Laura Bulgarelli, MS
(Georgia Institute of Technology)
Associate Dean of Finance and Administration

Lisa Camp, MS
(Case Western Reserve University)
Associate Dean of Strategic Initiatives

Daniel Ducoff, MS
(University of California, Berkeley)
Associate Dean of Development and Global Relations

Deborah J. Fatica, MA
(Bowling Green State University)
Assistant Dean of the Division of Engineering Leadership and Professional Practice

K. Peter D. Lagerlof, PhD
(Case Western Reserve University)
Faculty Director of Program Evaluation and Assessment

Clare M. Rinnac, PhD
(Lehigh University)
Associate Dean of Research and Wilbert J. Austin Professor of Engineering

Gary E. Wnek, PhD
(University of Massachusetts, Amherst)
Associate Dean of Academics and Joseph F. Toot, Jr., Professor of Engineering

Degree Program in Engineering, Undesignated

Engineering (Undesignated)

The Case School of Engineering offers undesignated degrees at the Undergraduate and Graduate level.

Bachelor of Science in Engineering (Undesignated)

The Engineering (Undesignated) 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 Engineering (Undesignated) 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. This is not an ABET accredited program.

A student electing an undesignated degree must submit a clear statement of career goals supported by a proposed course schedule with written justification for the selections. These documents are to be submitted to the office of the dean in the Case School of Engineering. The program must be approved by the associate dean in the Case School of Engineering in consultation with representatives of the major and minor departments. A total of at least 129 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 (<http://bulletin.case.edu/undergraduatelstudies/csdegree>)
2. A minimum of two engineering elective courses selected from two of the following four groups:

Thermodynamics or Physical Chemistry

ECHE 363	Thermodynamics of Chemical Systems	3
EMAC 351 & EMAC 352	Physical Chemistry for Engineering and Polymer Physics and Engineering	6
CHEM 301 & CHEM 302	Introductory Physical Chemistry I and Introductory Physical Chemistry II	6

Signals, systems or control

ECHE 367	Process Control	4
EECS 246 or EBME 308	Signals and Systems or Biomedical Signals and Systems	3-4
EECS 304	Control Engineering I with Laboratory	3

Materials science

EBME 306	Introduction to Biomedical Materials	3
EECS 321	Semiconductor Electronic Devices	4
EMAC 270	Introduction to Polymer Science and Engineering	3
EMSE 276	Materials Properties and Design	3
EMSE 343	Materials for Electronics and Photonics	3

Economics, production systems or decision theory

EECS 350	Operations and Systems Design	3
EECS 352	Engineering Economics and Decision Analysis	3
OPRE 345	Decision Theory	3

Major Field

The major field within the Engineering (Undesignated) requirements must contain a minimum of 24 credit-hours of work in one of the following engineering fields

- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Electrical Engineering
- Engineering Physics
- 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 Field

The minor field within the Engineering (Undesignated) requirements must contain a minimum of 15 credit-hours. Minors should be developed with the help of the associate dean in the Case School of Engineering. Minor fields must be approved by the department offering the minor.

Bachelor of Science in Engineering (Undesignated)

First Year	Units	
	Fall	Spring
Open elective or Humanities/Social Science ^a		3
Principles of Chemistry for Engineers (CHEM 111)		4
Elementary Computer Programming (ENGR 131) or Introduction to Programming in Java (EECS 132) or General Physics I - Mechanics (PHYS 121)		3-4
FSCC 100 SAGES First Seminar		4
Calculus for Science and Engineering I (MATH 121)		4
PHED Physical Education Activities		
Humanities/Social Science or open elective		3
Chemistry of Materials (ENGR 145)		4
Calculus for Science and Engineering II (MATH 122)		4
General Physics I - Mechanics (PHYS 121) or Elementary Computer Programming (ENGR 131)		3-4
PHED Physical Education Activities		
Year Total:	18-19	14-15
Second Year	Units	
	Fall	Spring
USXX SAGES University Seminar		3
Statics and Strength of Materials (ENGR 200)		3
Calculus for Science and Engineering III (MATH 223)		3
Numerical Methods (EECS 251)		3

General Physics II - Electricity and Magnetism (PHYS 122)	4	
USXX SAGES University Seminar		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)	4	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
Elementary Differential Equations (MATH 224)	3	
Introduction to Modern Physics (PHYS 221)	3	
Year Total:	16	17

Third Year**Units****Fall Spring**

Humanities or Social Science	3	
Major Concentration Course	3	
Major Concentration Course	3	
Minor Concentration Course	3	
Engineering elective	3	
Open elective	3	
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)		3
Major Concentration Course		3
Major Concentration Course		3
Minor Concentration Course		3
Engineering elective		3
Year Total:	18	15

Fourth Year**Units****Fall Spring**

Humanities or Social Science elective	3	
Exxx 398 Engineering Senior Project	1-3	
Major Concentration Course	3	
Minor Concentration Course	3	
Minor Concentration Course	3	
Humanities or Social Science elective		3
Major Concentration Course		3
Major Concentration Course		3
Minor Concentration Course		3
Open elective		3
Year Total:	13-15	15

Total Units in Sequence: 126-130

Hours required for graduation: 129

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

Master of Science in Engineering (Undesignated)

A student working toward an undesignated Master of Science degree in engineering must select a department. The student is responsible for submitting a Planned Program of Study via the Student Information System where it will be routed for appropriate approvals. The Planned Program of Study must contain a minimum of 9 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.

Department of Biomedical Engineering

The Department of Biomedical Engineering was established in 1968 at Case Western Reserve University. As one of the pioneer programs in the world, it has become 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 the program, which has been emulated by many other institutions. Quantitative engineering and analytic methods for biomedical applications remains the cornerstone of the program and distinguishes it from biomedical science programs. In addition to dealing with biomedical problems at the tissue and organ-system level, the department's 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 degree programs include the BS, MS, ME, combined BS/MS, PhD, MD/MS, and MD/PhD in biomedical engineering. In all of the BME programs at Case, 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 in close proximity on the same campus. The Biomedical Engineering faculty members carry joint appointments in the two schools and participate in the teaching, research, and decision-making committees of both. The department is close to several major medical centers (University Hospitals, Cleveland Clinic, VA Medical Center, and MetroHealth Medical Center). As a result, there is an unusually free flow of academic exchange and collaboration in research and education among the schools and institutions. All of Case Western Reserve's BME programs take full advantage of faculty cooperation among university departments, which adds significant strength to the programs.

Mission

To educate leaders who will integrate both principles of engineering and medicine to create knowledge and discoveries that advance human health and well-being. Our faculty and students play leading roles ranging from basic science discovery to the creation, clinical evolution, and commercialization of new technologies, devices, and therapies. In short, we are "Engineering Better Health."

Background

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.

Research

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 medical centers bring a broad range of opportunities, expertise, and perspective to student research projects.

Biomaterials/Tissue Engineering/Drug and Gene Delivery

Fabrication and analysis of materials for implantation, including neural, orthopaedic, and cardiovascular tissue engineering, biomimetic materials, liposomal and other structures for controlled, targeted drug delivery, and biocompatible polymer surface modifications. Analysis of synthetic and biologic polymers by AFM, nanoscale structure-function relationships of biomaterials. Applications in the nervous system, the cardiovascular system, the musculoskeletal system, and cancer.

Biomedical Imaging

MRI, PET, SPECT, CT, ultrasound, acoustic elastography, optical coherence tomography, cardiac electrical potential mapping, human visual perception, image-guided intervention, contrast agents. In vivo microscopic and molecular imaging, and small animal imaging.

Biomedical Sensing

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

Neural Engineering and Neural Prostheses

Neuronal mechanisms; neural interfacing for electric and magnetic stimulation and recording; neural dynamics, ion channels, second messengers; neural prostheses for control of limb movement, bladder, bowel, and respiratory function; computational modeling of neural structures.

Transport and Metabolic Systems Engineering

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

Biomechanical Systems

Computational musculoskeletal modeling, bone biomechanics, soft tissue mechanics, control of neuroprostheses for motor function, neuromuscular control systems, human locomotion, cardiac mechanics.

Cardiovascular Systems

Normal cardiac physiology, pathogenesis of cardiac diseases, therapeutic technologies; electrophysiological techniques, imaging technologies, mathematical modeling, gene regulation, molecular biology techniques; cardiac bioelectricity and cardiac biomechanics.

Major (p. 17) | Specialty Electives (p. 18) | BS/MS (p. 21) | Minor (p. 21)

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 Bachelor of Science degree program in Biomedical Engineering is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

Some BS 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 Track Courses. The Engineering Core provides a fundamental background in mathematics, sciences, and engineering. The BME Core integrates engineering with biomedical science to solve biomedical problems. Hands-on experience in BME is developed through undergraduate laboratory and project courses. In addition, by choosing BME Track Courses, the student can study a specific area in depth. 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.

Program Educational Objectives

At the undergraduate level, we direct our efforts toward two educational objectives that describe the performance of alumni 3-6 years after graduation.

1. Our graduates will successfully enter and complete post-baccalaureate advanced degree programs, including those in biomedical engineering.
2. Our graduates will obtain jobs in the biomedical arena and advance to positions of greater responsibility.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Biomedical Engineering is designed so that students attain:

- An ability to apply knowledge of mathematics, science, and engineering appropriate to the biomedical engineering
- An ability to design and conduct experiments, as well as to analyze and interpret data
- An ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- An ability to function on multi-disciplinary teams
- An ability to identify, formulate, and solve engineering problems
- An understanding of professional and ethical responsibility
- An ability to communicate effectively
- The ability to communicate the impact of engineering solutions in a global, economic, environmental, and societal context
- A recognition of the need for, and an ability to engage in life-long learning
- A knowledge of contemporary issues
- An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Bachelor of Science in Engineering

Major in Biomedical Engineering

Majors in Biomedical Engineering choose a specialization sequence, with sequence-specific courses. More information can be obtained from the Department of Biomedical Engineering (<http://bme.case.edu>).

Required Courses

Major Courses

EBME 201	Physiology-Biophysics I	3
EBME 202	Physiology-Biophysics II	3
EBME 306	Introduction to Biomedical Materials	3
EBME 308	Biomedical Signals and Systems	3
EBME 309 & EBME 359	Modeling of Biomedical Systems and Biomedical Computer Simulation Laboratory	4
EBME 310 & EBME 360	Principles of Biomedical Instrumentation and Biomedical Instrumentation Laboratory	4
EBME 370	Principles of Biomedical Engineering Design	2
EBME 380	Biomedical Engineering Design Experience	3
Plus one of the following two sequences:		2
EBME 318 & EBME 319	Biomedical Engineering Laboratory I and Biomedical Engineering Laboratory II	
EBME 328 & EBME 329	Biomedical Engineering R&D Training I and Biomedical Engineering R&D Training II	
One of the following statistics courses:		3
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	
Plus 7 Specialty Track specialization courses		22-23
Total Units		52-53

Biomedical Engineering Specialty Electives

BME Courses for these tracks are presented in the tables below; more information can be obtained from the Department of Biomedical Engineering (<http://bme.case.edu>). These tracks 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.

Biomedical Devices and Instrumentation Track

EECS 245	Electronic Circuits	4
EECS 281	Logic Design and Computer Organization	4
EECS 309	Electromagnetic Fields I	3
EECS 344	Electronic Analysis and Design	3
EBME 105	Introduction to Biomedical Engineering (or Open Elective)	3
Math or Science Elective		3
Approved Tech Elective		3
Approved Tech Elective		3
Approved Tech Elective		3
Choose one of the following two courses:		3
EBME 327	Bioelectric Engineering	
EBME 320	Medical Imaging Fundamentals	

The following courses are approved technical electives for the Biomedical Devices and Instrumentation track. Any other technical course can be approved by the track leader and the student's advisor, if it fits better with the student's career plans.

Electronics:	
EECS 321	Semiconductor Electronic Devices

EECS 322	Integrated Circuits and Electronic Devices	
EBME 418	Electronics for Biomedical Engineering	
Software:		
EECS 233	Introduction to Data Structures	
EECS 337	Compiler Design	
EECS 338	Introduction to Operating Systems	
EECS 340	Algorithms	
EECS 351	Communications and Signal Analysis	
EECS 354	Digital Communications	
Modeling/Simulation:		
EECS 324	Modeling and Simulation of Continuous Dynamical Systems	
EECS 346	Engineering Optimization	
EBME 478	Computational Neuroscience	
EBME 401	Biomedical Instrumentation and Signal Analysis	
Other:		
EBME 407	Neural Interfacing	
EBME 408	Engineering Tissues/Materials - Learning from Nature's Paradigms	
EECS 304	Control Engineering I with Laboratory	
EBME 350	Quantitative Molecular, Cellular and Tissue Bioengineering	
Choose one of the following:		3
EBME 327	Bioelectric Engineering	
EBME 320	Medical Imaging Fundamentals	
EBME 398	Senior Project Laboratory I	

*To receive a minor in EECS, two (2) of the Tech Electives must be from EECS

Biomaterials Track

CHEM 223	Introductory Organic Chemistry I	3
EMAC 270	Introduction to Polymer Science and Engineering	3
EMAC 351	Physical Chemistry for Engineering	3
EMAC 355	Polymer Analysis Laboratory	3
EBME 105	Introduction to Biomedical Engineering ((or Open Elective))	3
Math or Science Elective		3
Approved Tech. Elective		3
Approved Tech. Elective		3
Approved Tech. Elective		3
Choose one from the following four courses:		3
EBME 406	Polymers in Medicine	
EBME 316	Biomaterials for Drug Delivery	
EBME 325	Introduction to Tissue Engineering	
EBME 305	Materials for Prosthetics and Orthotics	

The following courses are approved technical electives for the Biomaterials track. Any other technical course can be approved by the track leader and the student's advisor, if it fits better with the student's career plans.

Polymeric Biomaterials	
EMAC 276	Polymer Properties and Design
EMAC 370	Polymer Chemistry
EMAC 376	Polymer Engineering
EMAC 377	Polymer Processing

EBME/EMAC 303	Structure of Biological Materials
EBME 305	Materials for Prosthetics and Orthotics
EBME 350	Quantitative Molecular, Cellular and Tissue Bioengineering
EBME 406/ EMAC 471	Polymers in Medicine
EBME 408	Engineering Tissues/Materials - Learning from Nature's Paradigms
EBME 315	Applied Tissue Engineering
EBME 325	Introduction to Tissue Engineering
EBME 408	Engineering Tissues/Materials - Learning from Nature's Paradigms
EBME 425	Tissue Engineering and Regenerative Medicine
Hard Materials	
EMAE 160	Mechanical Manufacturing
EMSE 307	Foundry Metallurgy
EMSE 313	Engineering Applications of Materials
EMSE 335	Strategic Metals and Materials for the 21st Century
EMSE 411	Environmental Effects on Materials
EBME 316	Biomaterials for Drug Delivery
EBME 426	Nanomedicine
ECHE 474	Biotransport Processes
ECHE 340	Biochemical Engineering
ECHE 360	Transport Phenomena for Chemical Systems
ECHE 364	Chemical Reaction Processes
EMAC 376	Polymer Engineering
Other:	
EBME 398	Senior Project Laboratory I

Biomechanics Track

EMAE 181	Dynamics	3
ECIV 310	Strength of Materials	3
EMAE 290	Computer-Aided Manufacturing	3
EBME 105	Introduction to Biomedical Engineering (or Open Elective)	3
Math or Science Elective		3
Approved Tech Elective		3
Approved Tech Elective		3
Approved Tech Elective		3
Choose one of the following:		3
EBME 307	Biomechanical Prosthetic Systems	
EMAE 160	Mechanical Manufacturing	

The following courses are approved technical electives for the Biomechanics track. Any other technical course can be approved by the track leader and the student's advisor, if it fits better with the student's career plans.

EMAE 250	Computers in Mechanical Engineering
EMAE 390	Advanced Manufacturing Technology
EMAE 370	Design of Mechanical Elements
EMAE 372	Structural Materials by Design
EMAE 350	Mechanical Engineering Analysis
EMAE 415	Introduction to Musculo-skeletal Biomechanics
EBME 305	Materials for Prosthetics and Orthotics

EBME 402	Organ/Tissue Physiology and Systems Modeling
ECIV 420	Finite Element Analysis
EBME 398	Senior Project Laboratory I

Biomedical Computing and Analysis Track

EECS 302	Discrete Mathematics	3
EECS 233	Introduction to Data Structures	4
MATH 201	Introduction to Linear Algebra	3
EECS 324	Modeling and Simulation of Continuous Dynamical Systems	3
EBME 105	Introduction to Biomedical Engineering (or Open Elective)	3
Math or Science Elective		3
Approved Tech. Elective		3
Approved Tech. Elective		3
Approved Tech. Elective		3
Choose one of the following four classes:		3

EBME 327	Bioelectric Engineering
EBME 350	Quantitative Molecular, Cellular and Tissue Bioengineering
EBME 307	Biomechanical Prosthetic Systems

Computing/Imaging:

EBME 461	Biomedical Image Processing and Analysis
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The following courses are approved technical electives for the biomedical computing and analysis track. Any other technical course can be approved by the track leader and the student's advisor, if it fits better with the student's career plans.

To receive a minor in Systems Engineering, students must choose EECS 304, EECS 346, and EECS 352 for tech. electives and either EECS 350 or EECS 391 for an open tech. elective.

EECS 304	Control Engineering I with Laboratory
EECS 346	Engineering Optimization
EBME 300	Dynamics of Biological Systems: A Quantitative Introduction to Biology
EECS 350	Operations and Systems Design
EECS 352	Engineering Economics and Decision Analysis
EECS 359	Bioinformatics in Practice
EECS 391	Introduction to Artificial Intelligence
EBME 398	Senior Project Laboratory I

Biomedical Computing & Imaging

To receive a minor in Computer Science, students must choose EECS 338 and EECS 340 for two of the tech. electives.

EECS 281	Logic Design and Computer Organization
EECS 293	Software Craftsmanship
EECS 313	Signal Processing
EECS 338	Introduction to Operating Systems
EECS 340	Algorithms
EECS 341	Introduction to Database Systems
EECS 343	Theoretical Computer Science
EECS 359	Bioinformatics in Practice
EECS 391	Introduction to Artificial Intelligence
EECS 394	Introduction to Information Theory
EBME 398	Senior Project Laboratory I

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 five-year program. Alternatively, students may obtain employment as summer interns.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Biomedical Engineering

First Year	Units	
	Fall	Spring
Introduction to Biomedical Engineering (EBME 105) ^b	3	
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121)	4	
Elementary Computer Programming (ENGR 131/ EECS 132) ^h	3	
SAGES First Seminar (FSxx)	4	
PHED (2 half semester courses)		
Chemistry of Materials (ENGR 145)	4	
Calculus for Science and Engineering II (MATH 122)	4	
General Physics I - Mechanics (PHYS 121)	4	
USxx University Seminar ^c	3	
PHED (2 half semester courses)		
Year Total:	18	15
Second Year	Units	
	Fall	Spring
Physiology-Biophysics I (EBME 201)	3	
Calculus for Science and Engineering III (MATH 223)	3	
General Physics II - Electricity and Magnetism (PHYS 122)	4	
One of the following:	3	
BME Track Course ^d		
Science elective ^e		
USxx University Seminar ^c	3	
Physiology-Biophysics II (EBME 202)	3	
Elementary Differential Equations (MATH 224)	3	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
One of the of following:	3	
BME Track Course ^d		
Science elective ^e		
SAGES Breadth Requirement (Arts and Humanities or Social Science Course)	3	
Year Total:	16	16
Third Year	Units	
	Fall	Spring
Introduction to Biomedical Materials (EBME 306)	3	
Biomedical Engineering Laboratory I (EBME 318) or Biomedical Engineering R&D Training I (EBME 328)	1	

Professional Communication for Engineers (ENGL 398)	3	
& Professional Communication for Engineers (ENGR 398)		
Biomedical Signals and Systems (EBME 308)	3	
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)	4	
Biomedical Engineering Laboratory II (EBME 319) or Biomedical Engineering R&D Training II (EBME 329)	1	
Principles of Biomedical Instrumentation (EBME 310)	3	
Biomedical Instrumentation Laboratory (EBME 360)	1	
Statics and Strength of Materials (ENGR 200)	3	
Modeling of Biomedical Systems (EBME 309) & Biomedical Computer Simulation Laboratory (EBME 359)	4	
BME Track Course ^d	3	
BME Track Course ^d	3	
Year Total:	14	18

Fourth Year	Units	
	Fall	Spring
H/SS ⁱ	3	
Principles of Biomedical Engineering Design (EBME 370)	2	
BME Track Course ^d	3	
BME Track Course ^d	3	
Statistics ^g	3	
H/SS ⁱ	3	
Open Elective	3	
H/SS ⁱ	2	
BME Track Course ^d	3	
H/SS ⁱ	1	
Biomedical Engineering Design Experience (EBME 380)	3	
BME Track Course ^d	3	
Year Total:	17	15

Total Units in Sequence: 129

- This is a typical program. Track courses are designed with courses in a desired order that might vary from the one here. Programs must be planned with a faculty advisor in the Department of Biomedical Engineering.
- This optional course is limited to freshmen. This can be replaced by an open elective.
- University Seminars (6 semester hours, minimum of 2 seminars selected from different thematic groups and different thematic group from that of FSCC 100 First Seminar).
- Courses are chosen depending on the BME track courses as listed below.
- Students take at least one math or science course approved by BME department.

- f SAGES BME Departmental Seminar, ENGL 398 Professional Communication for Engineers and ENGR 398 Professional Communication for Engineers must be taken together.
- g STAT 312 Basic Statistics for Engineering and Science, STAT 333 Uncertainty in Engineering and Science, or STAT 332 Statistics for Signal Processing fulfill the statistics requirement. Check with sequence advisor to determine the most appropriate class.
- h Students interested in Biomedical Computing and Analysis are required to take EECS 132.
- i Humanities/Social Science course

BS/MS Program

Undergraduates with a strong academic record may apply in their junior year for admission to the integrated BS/MS program. A senior research project that begins in the summer after the junior year is designed to expand into an MS 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 BS and MS in five years.

Minor in Biomedical Engineering

A minor in biomedical engineering is offered to students who have taken the Engineering Core requirements. The minor consists of an approved set of five EBME courses.

Required Courses

EBME 201	Physiology-Biophysics I	3
EBME 202	Physiology-Biophysics II	3
Two of the following:		6
EBME 306	Introduction to Biomedical Materials	
EBME 309	Modeling of Biomedical Systems	
EBME 310	Principles of Biomedical Instrumentation	
One of the following:		3
EBME 303	Structure of Biological Materials	
EBME 307	Biomechanical Prosthetic Systems	
EBME 320	Medical Imaging Fundamentals	
EBME 322	Applications of Biomedical Imaging	
EBME 350	Quantitative Molecular, Cellular and Tissue Bioengineering	
Total Units		15

Graduate Programs

The objective of the graduate program in biomedical engineering 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 at Case enables 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.

Graduate Certificates

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings:

- **Health Informational Technology**
- **Wireless Health**
- **Wireless Health Product Development**

For more details, please refer to the Graduate Certificate (<http://engineering.case.edu/sandiego/gcacademics>) information on the Case School of Engineering - San Diego website.

Master of Science in Engineering

The MS 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 MS requires a minimum of 27 credit hours. With an MS research thesis (Plan A), a minimum of 18 credits hours is needed in regular course work and 9 hours of thesis research (EBME 651 Thesis M.S.). With an MS project (Plan B), a minimum of 24 credits hours is needed in regular course work, and three hours of project research (EBME 601 Research Projects); or this can be accomplished in 27 credit hours of coursework with a comprehensive final exam for the degree.

Master of Science in Engineering with Specialization

Translational Health Technology

This Masters degree in Biomedical Engineering is designed to develop expertise in translating biomedical ideas into clinical implementation. This degree can be completed in one year for full time students. It is offered by the Biomedical Engineering department in the Case School of Engineering, and takes advantage of the large pool of expertise in Biotechnology on the campus of Case Western Reserve University. It combines aspects of **bioengineering**, **marketing**, **entrepreneurship**, and **bioregulatory affairs** with **ethics** and **experimental design**. The program will require students to take a minimum of 27 credits including a design project.

Prerequisite: Biomedical Engineering Degree or equivalent or consent of program director.

Special Features:

- Eight courses plus 4 hours of project
- Portions available through Distance Learning
- Flexible program to accommodate a professional's schedule
- Lock-Step Program; Duration 1 year: August to August
- Projects can be done within the place of work

Wireless Health

The **MS degree in Biomedical Engineering** (BME) with a specialization in Wireless Health is a "course-only" or "Thesis-option" program of study.

Students who complete the 9-course, 27-credit course-only option or the 6-course-plus-thesis, 27-credit thesis-based option will have the requisite knowledge to enter and advance the wireless health industry.

For more details, please refer to the Master's Degree (<http://engineering.case.edu/sandiego/academics>) information on the Case School of Engineering - San Diego website.

MD/MS Program

Medicine is undergoing a transformation based on the rapid advances in science and technology that are combining to produce more accurate diagnoses, more effective treatments with fewer side effects, and improved ability to prevent disease. The goal of the MD/MS in Engineering is to prepare medical graduates to be leaders in the development and clinical deployment of this technology and to partner with others in technology based translational research teams. Current Case medical students in either the University Program (UP) or the Cleveland Clinic Lerner College of Medicine (CCLCM) may apply to the MD/MS in Engineering program.

Students must complete the normal requirements in their particular MD program. Portions of the medical school curriculum earn graded credit toward the MD/MS degree. Specifically, six credit hours of the medical school curriculum can be applied to the MS component of the joint degree.

The balance of 12 credit hours (4 courses) must be graduate level engineering concentration courses that provide rigor and depth in a field of engineering relevant to the area of research.

A required thesis (9 credit hours of EBME 651 Thesis M.S.) serves a key integration role for the joint degree, with both medical and engineering components. The thesis also fulfills the research requirement of the UP or CCLCM programs.

Students should apply through the BME department admissions office.

PhD Program in Biomedical Engineering

For those students with primary interest in research, the PhD 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 PhD program requires a minimum of 36 credit hours of courses beyond the BS degree. There are 12 credit hours of required core courses. 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 one graduate level course in biomedical sciences and one course whose content is primarily mathematical. Two semesters of departmental seminar attendance (EBME 611 BME Departmental Seminar I, EBME 612 BME Departmental Seminar II), two semesters of topic seminar (EBME 612-620), a professional development class (EBME 570 Graduate Professional Development for Biomedical Engineers), and three semesters of teaching experience (EBME 400T Graduate Teaching I, EBME 500T Graduate Teaching II, and EBME 600T Graduate Teaching III) are also required. PhD programs of study are reviewed and must be accepted by the Graduate Education Committee and the department

chair. Eighteen hours of EBME 701 Dissertation Ph.D. registration are required.

PhD candidacy requires passing certain milestones. A student is advanced to PhD candidacy after: (1) passing the graduate core classes with a "B" or better; (2) passing the Oral Qualifying Exam; and (3) writing and defending a research proposal exam. The PhD is completed when the dissertation has been written and defended, and when at least three peer-reviewed manuscripts have been submitted (only two require first authorship) for publication and at least two are published or accepted for publication.

MD/PhD Programs

Students with outstanding qualifications may apply to either of two MD/PhD programs. Students interested in obtaining a combined MD/PhD, 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. The MD/PhD programs require approximately 7-8 years of intensive study after the BS. Interested students should apply through the MSTP office in the Medical School.

Facilities

The home of the Department of Biomedical Engineering is primarily located in Wickenden Building, with offices for over 90 percent of all primary faculty members and staff, as well as most of the non-clinical research laboratories and centers. Major interdisciplinary centers include: the Center for Biomaterials, the Neural Engineering Center (NEC), and the In-situ Imaging Center. The Center for Biomaterials includes laboratories for biomaterials microscopy, biopolymer and biomaterial interfaces, and molecular simulation. The NEC is a major facility for basic research and animal experimentation, with a focus on recording and controlling neural activity to increase our understanding of the nervous system and to develop neural prostheses. The Biomedical Imaging Laboratories, housed in the Case Center for Imaging Research and the Department of Radiology at University Hospitals, image structure and function from the molecular level to the tissue-organ level, using many modalities, including ultrasound, MRI, CT, PET, SPECT, bioluminescence, and light. Biomedical sensing laboratories include facilities for electrochemical sensing, chemical measurements in individual cells, and minimally invasive physiological monitoring.

Primary BME faculty members also have laboratories and centers in other locations. The Endoscopy Research Laboratory in University Hospitals is the center for work on optical coherence tomography and biophotonics. The FES (Functional Electrical Stimulation) Center, with laboratories in three medical centers, 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 functional electrical stimulation, and evaluates clinical functionality of neuroprostheses. The APT (Advanced Platform Technology) Center develops advanced technologies that serve the clinical needs of veterans and others with motor and sensory deficits and limb loss.

The Coulter-Case Translation and Innovation Partnership (CCTRP) is a department-based collaboration with the Wallace H. Coulter Foundation. The program fosters collaborations between clinicians and the Case Western Reserve University biomedical engineering faculty on translational research projects with the potential to impact patient care often through the creation of new biomedical products and new product concepts.

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

Primary Appointments

Robert F. Kirsch, PhD
(Northwestern University)

Professor and Interim Chair; Executive Director, Functional Electrical Stimulation Center

Restoration of movement using neuroprostheses; neuroprosthesis control system design; natural control of human movements; biomechanics of movement; computer-based modeling; and system identification

A. Bolu Ajiboye, PhD
(Northwestern University)

Assistant Professor

Development and control of brain-computer-interface (BCI) technologies for restoring function to individuals with nervous system injuries

Eben Alsberg, PhD
(University of Michigan)

Associate Professor

Biomimetic tissue engineering; innovative biomaterials and drug delivery vehicles for functional tissue regeneration and cancer therapy; control of stem cell fate decision; precise temporal and spatial presentation of signals to regulate cell behavior; mechanotransduction and the influence of mechanics on cell behavior and tissue formation; and cell-cell interactions

James P. Babilion, PhD
(The University of Texas)

Associate Professor (joint with Radiology)

High resolution imaging of endogenous gene expression; definition of "molecular signatures" for imaging and treatment of cancer and other diseases; generating and utilizing genomic data to define informative targets; strategies for applying non-invasive imaging to drug development; and novel molecular imaging probes and paradigms

Jeffrey Capadona, PhD
(Georgia Institute of Technology)

Assistant Professor

Advanced materials for neural interfacing; biomimetic and bio-inspired materials; host-implant integration; anti-inflammatory materials; and novel biomaterials for surface modification of cortical neuroprostheses

Patrick E. Crago, PhD
(Case Western Reserve University)

Professor

Control of neuroprostheses for restoration of motor function; neuromechanics; and modeling of neuromusculoskeletal systems

Jeffrey L. Duerk, PhD
(Case Western Reserve University)

Dean, Case School of Engineering; Leonard Case Professor of Engineering; Director, Case Center for Imaging Research

Magnetic resonance imaging; rapid magnetic resonance imaging pulse sequence development; image reconstruction from non-rectilinearly sampled data; the development of image-guided interventional MRI procedures, including percutaneous cancer and cardiovascular procedures

Dominique M. Durand, PhD
(University of Toronto, Canada)

Elmer Lincoln Lindseth Professor in Biomedical Engineering; Director, Neural Engineering Center

Neural engineering; neural interfacing; neural prostheses; computational neuroscience; neural dynamics; neuromodulation; neurophysiology and control of epilepsy

Steven J. Eppell, PhD
(Case Western Reserve University)

Associate Professor

Biomaterials; instrumentation; nanoscale structure-function analysis of orthopaedic biomaterials; and scanning probe microscopy and spectroscopy of skeletal tissues

Miklos Gratzl, PhD
(Technical University of Budapest, Hungary)

Associate Professor

Biomedical sensing and diagnostics in vitro and in vivo; electrochemical and optical techniques; BioMEMS for cellular transport; cancer multi-drug resistance at the single cell level; and sliver sensor for multi-analyte patient monitoring

Kenneth Gustafson, PhD
(Arizona State University)

Associate Professor

Neural engineering; neural prostheses; neurophysiology and neural control of genitourinary function; devices to restore genitourinary function; and functional neuromuscular stimulation

Efstathios (Stathis) Karathanasis, PhD
(University of Houston)

Assistant Professor

Fabricating multifunctional agents that facilitate diagnosing; treating and monitoring of therapies in a patient-specific manner

Erin Lavik, ScD
(Massachusetts Institute of Technology)

Elmer Lincoln Lindseth Associate Professor in Biomedical Engineering

Biomaterials; synthesis of new degradable polymers; tissue engineering; spinal cord repair; retinal regeneration; and drug delivery for optic nerve preservation and repair

Zheng-Rong Lu, PhD
(Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences)

M. Frank and Margaret Domiter Rudy Professor of Biomedical Engineering

Drug delivery and molecular imaging; novel targeted imaging agents for molecular imaging; novel MRI contrast agents; image-guided therapy and drug delivery; polymeric drug delivery systems; multi-functional delivery systems for nucleic acids

Anant Madabhushi, PhD
(Rutgers University)

Professor

Quantitative image analysis; Multi-modal, multi-scale correlation of massive data sets for disease diagnostics, prognostics, theragnostics; cancer applications

Cameron McIntyre, PhD
(Case Western Reserve University)

Assistant Professor, Molecular Medicine

Theoretical modeling of the interaction between electric fields and the nervous system; deep brain stimulation

J. Thomas Mortimer, PhD
(Case Western Reserve University)

Professor Emeritus

Neural control and prostheses; electrical activation of neural tissue; and membrane properties and electrodes

P. Hunter Peckham, PhD
(Case Western Reserve University)

Donnell Institute Professor; Distinguished University Professor;

Rehabilitation engineering in spinal cord injury; neural prostheses; and functional electrical stimulation and technology transfer

Andrew M. Rollins, PhD
(Case Western Reserve University)

Associate Professor

Biomedical optics; real-time in-vivo microstructural, functional, and molecular imaging using optical coherence tomography; diagnosis and guided therapy for cancer, cardiovascular, and ophthalmic disease

Gerald M. Saidel, PhD
(The Johns Hopkins University)

Professor; Director, Center for Modeling Integrated Metabolic Systems

Mass and heat transport and metabolism in cells, tissues, and organ systems; mathematical modeling and simulation of dynamic and spatially distributed systems; optimal nonlinear parameter estimation and design of experiments

Nicole Seiberlich, PhD
(University of Wurzburg)

Assistant Professor

Advanced signal processing and data acquisition techniques for rapid Magnetic Resonance Imaging (MRI).

Anirban Sen Gupta, PhD
(The University of Akron)

Associate Professor

Targeted drug delivery; targeted molecular imaging; image-guided therapy; platelet substitutes; novel polymeric biomaterials for tissue engineering scaffolds

Nicole F. Steinmetz, PhD
(John Innes Centre in Norwich, UK)

Assistant Professor

Engineering of viral nanoparticles as smart devices for applications in medicine: tissue-specific imaging, drug-delivery, and tissue engineering

Dustin J. Tyler, PhD
(Case Western Reserve University)

Associate Professor

Neuromimetic neuroprostheses; laryngeal neuroprostheses; clinical implementation of nerve electrodes; cortical neuroprostheses; minimally invasive implantation techniques; and modeling of neural stimulation and neuroprostheses

Horst A. von Recum, PhD
(University of Utah)

Associate Professor

Affinity-based delivery of small molecule drugs and biomolecules for applications in device infection, HIV, orthopedics, cardiovascular, ophthalmology and cancer; directed differentiation of stem cells for tissue engineering applications, such as endothelial cells, cardiomyocytes, motor neurons and T-cells

David L. Wilson, PhD
(Rice University)

Robert J. Herbold Professor

Biomedical image processing; digital processing and quantitative image quality of X-ray fluoroscopy images; interventional MRI

Xin Yu, ScD
(Harvard-MIT)

Associate Professor

Magnetic resonance imaging and spectroscopy; applications of MRI and MRS to cardiovascular research

Secondary Appointments

Rigoberto Advincula, PhD
(University of Florida)

Professor

Design, synthesis, and characterization of polymers and nanostructured materials capable of controlled-assembly, tethering, and self-organization in ultrathin films.

Ozan Akkus, PhD
(Case Western Reserve)

Associate Professor

Development of novel biomaterials that will substitute bone and soft tissues, bioinspired from the synthesis of bone such that ductile biocompatible polymer matrices are subjected to mineralization. Tendon replacement strategy involve alignment of collagen monomers by a novel electrochemical method to obtain strong bundles.

Jay Alberts, PhD
(Arizona State University)

Assistant Professor of Biomedical Engineering (Cleveland Clinic)

Neural basis of upper extremity motor function and deep brain stimulation in Parkinson's disease

James M. Anderson, MD (Case Western Reserve University), PhD
(Oregon State University)

Professor, Pathology, University Hospitals-Case Medical Center

Blood and tissue/material interactions as they relate to implantable devices and biomaterials

Harihara Baskaran, PhD
(Pennsylvania State University)

Assistant Professor, Chemical and Biomolecular Engineering
Design and build microvascular flow analogs that can be used to overcome nutrient limitations in tissue-engineered products

Jonathan Baskin, MD
(New York University)

Assistant Professor, Chief, Otolaryngology-Head & Neck Surgery, University Hospitals-Case Medical Center, VA Medical Center
Bioengineering of bone substitutes using nanotechnology

Arnold Caplan, PhD
(Johns Hopkins University)

Professor, Biology
Develop and refine the technology necessary to isolate one of these rare stem cells, the mesenchymal stem cell (MSC)

M. Cenk Cavusoglu, PhD
(University of California, Berkeley)

Professor, Electrical Engineering & Computer Science
Robotics, systems and control theory, and human-machine interfaces; with emphasis on medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

Ronald L. Cechner, Clinical PhD (Anesthesiology)
(Case Western Reserve University)

Assistant Professor, Anesthesiology and Associate Professor, Biomedical Engineering and Pathology, Technical Director, Anesthesia Simulation Laboratory, University Hospitals-Case Medical Center
Simulation in medical education

John Chae, MD
(New Jersey Medical School)

Professor, Physical Medicine and Rehabilitation, MetroHealth Medical Center
Stroke rehabilitation, neuromuscular electrical stimulation to restore upper and lower extremity function after stroke

Hillel J. Chiel, PhD
(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

Guy Chisolm, PhD
(University of Virginia)

Professor, Cell Biology, Cleveland Clinic
Vascular biology; lipoprotein-cell interactions

Margot Damaser, PhD
(University of California)

Associate Professor, Biomedical Engineering, Cleveland Clinic
Biomechanics and neural control of the female pelvic floor and lower urinary tract in normal and dysfunctional cases

James Dennis, PhD
(Case Western Reserve University)

Assistant Professor, Orthopaedics, University Hospitals-Case Medical Center
Engineering cartilage for orthopaedic and trachea reconstruction applications; developing reagents, termed "cell paints," that can be used to direct repair cells to specific organs and tissues

Kathleen Derwin, PhD
(University of Michigan)

Assistant Professor, Molecular Medicine (Biomedical Engineering, Cleveland Clinic)
Tendon mechanobiology and tissue engineering

Isabelle Deschenes, PhD
(Laval University)

Assistant Professor, Cardiology, MetroHealth Medical Center
Molecular mechanisms of cardiac arrhythmias, ion channels structure-function

Agata Exner, PhD
(Case Western Reserve University)

Associate Professor, Radiology, University Hospitals-Case Medical Center
Development and imaging characterization of drug delivery for cancer chemotherapy; interventional radiology

Elizabeth Fisher, PhD
(Rutgers University)

Associate Professor, Molecular Medicine (Biomedical Engineering, Cleveland Clinic)
Quantitative image analysis for application to multiple sclerosis and neurodegenerative diseases

Christopher Flask, PhD
(Case Western Reserve University)

Assistant Professor, Radiology, University Hospitals-Case Medical Center
Development of Quantitative and Molecular MRI Imaging Methods, MRI Physics

Kiyotaka Fukamachi, MD, PhD
(Kyushu University)

Professor
Research activities entail promoting human health through the development of various surgical treatments for heart failure, encompassing a broad range of options

Linda M. Graham, MD
(University of Michigan)

Professor, Surgery (Vascular Surgery and Biomedical Engineering), Cleveland Clinic
Cell movement and vascular healing, vascular tissue engineering

Mark Griswold, PhD
(University of Wuerzburg, Germany)

Associate Professor, Radiology, University Hospitals-Case Medical Center
Rapid magnetic resonance imaging, image reconstruction and processing and MRI hardware/instrumentation

Vikas Gulani, MD, PhD
(University of Illinois)
Assistant Professor, Radiology, University Hospitals-Case Medical Center
Diffusion tensor imaging and diffusion anisotropy, MRI microscopy, body MRI, and functional MRI

Alex Y. Huang, MD, PhD
(Johns Hopkins University)
Assistant Professor, Pediatrics, Pathology, University Hospitals-Case Medical Center/Rainbow Babies and Children's Hospital
Study various aspects of anti-tumor immune responses, immune – host – pathogen interaction, T cell-mediated memory immunity, and chemokine - receptor biology

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

Kandice Kottke-Marchant, MD, PhD
(Case Western Reserve University)
Professor, Molecular Medicine (Pathology and Laboratory Medicine, Cleveland Clinic)
Thrombosis, hemostasis and vascular disease, hypercoagulable states, bleeding disorders, endothelial cell function, atherosclerosis

Vinod Labhasetwar, PhD
(Nagpur University, India)
Associate Professor, Molecular Medicine (Biomedical Engineering, Cleveland Clinic)
Cancer treatment and detection, delivery of anti-oxidant enzymes in stroke and development of a non-stent approach to inhibition of restenosis

Kenneth R. Laurita, PhD
(Case Western Reserve University)
Associate Professor, Heart and Vascular Research Center, MetroHealth Medical Center
Cellular mechanisms of cardiac arrhythmias using fluorescent imaging of transmembrane potential and intracellular calcium in the intact heart

Zhenghong Lee, PhD
(Case Western Reserve University)
Associate Professor, Radiology, Nuclear Medicine, University Hospitals-Case Medical Center
Quantitative PET and SPECT imaging, multimodal image registration, 3D visualization, molecular imaging and small animal imaging systems

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

Kenneth Loparo, PhD
(Case Western Reserve University)
Nord Professor of Engineering, Electrical Engineering & Computer Science
Stability and control of nonlinear and stochastic systems; systems biology

Mehran Mehregany, PhD
(Massachusetts Institute of Technology)
Professor, Electrical Engineering & Computer Science
Micro/Nano-Electro-Mechanical Systems; silicon carbide semiconductor technology and microsystems; wireless health

Pedram Mohseni, PhD
(University of Michigan)
Assistant Professor, Electrical Engineering & Computer Science
Biomicrosystems; biomedical microtelemetry; biological-electronic interfaces; microelectronics for neurotechnology; and wireless integrated sensing/actuating systems

George F. Muschler, MD
(Northwestern University)
Professor, Molecular Medicine (Orthopaedic Surgery and Biomedical Engineering, Cleveland Clinic)
Bone biology, skeletal reconstruction, aging and osteoporosis

Raymond F. Muzic Jr., PhD
(Case Western Reserve University)
Associate Professor, Radiology, Biomedical Engineering, Oncology, Division of General Medical Sciences, University Hospitals-Case Medical Center
Quantitative analysis of biomedical imaging data, physiologic modeling, optimal experiment design, assessment of new radiopharmaceuticals, imaging response to therapy, and in vivo quantification of receptor concentration

Marc Penn, MD, PhD
(Case Western Reserve University)
Assistant Professor, Molecular Medicine (Cardiology and Cell Biology, Cleveland Clinic)
Myocardial ischemia, vascular biology, cardiac critical care

Clare Rimnac, PhD
(Lehigh University)
Professor, Mechanical and Aerospace Engineering
Orthopaedic implant performance and design, mechanical behavior of hard tissues

Stuart Rowan, PhD
(University of Glasgow, UK)
Kent Hale Smith Professor, Macromolecular Science & Engineering
Investigation and utilization of Supramolecular Chemistry (the chemistry of the non-covalent bond) in polymer chemistry

Mark S. Rzeszutarski, PhD
(Case Western Reserve University)
Professor, Radiology, MetroHealth Medical Center
Radiological imaging; computed tomography, medical education

Dawn Taylor, PhD
(Arizona State University)
Assistant Professor, Molecular Medicine (Neurosciences, Cleveland Clinic)
Restoration of movement and function to paralysis victims through the application of electrical current to the peripheral nerves

Ronald J. Triolo, PhD
(Drexel University)
Associate Professor, Orthopaedics, University Hospitals-Case Medical Center, VA Medical Center, MetroHealth Medical Center
Neural prostheses, rehabilitation engineering and restoration of lower extremity function, biomechanics of human movement quantitative analysis and control of gait, standing balance and seated posture

Albert L. Waldo, MD
(State University of New York, Downstate)
Professor, Medicine/Cardiology, University Hospitals-Case Medical Center
Cardiac electrophysiology and cardiac excitation mapping

Michael Weiss, MD, PhD, MBA
(Harvard Medical School, Case Western Reserve University)
Professor
Protein engineering: design of more stable proteins for use in novel devices and design of less stable proteins for use in artificial operons in genetic model organisms. The use of multi-dimensional MR spectroscopy to interrogate the outcomes of such protein engineering efforts.

Barry Wessels, PhD
(University of Notre Dame)
Professor, Biomedical Engineering and Radiation Oncology; Director, Division of Medical Physics and Dosimetry, University Hospitals-Case Medical Center
Radiolabeled antibody therapy (Dosimetry and clinical trials), image-guided radiotherapy, intensity modulated radiation therapy, image fusion of CT, MR, SPECT and PET for adaptive radiation therapy treatment planning

Xiong Yu, PhD, P.E.
(Purdue University School of Civil Engineering)
Associate Professor
Materials and sensors innovations with emphasis on interdisciplinary innovation to improve intelligent and durability

Guang Hui Yue, PhD
(University of Iowa)
Associate Professor, Molecular Medicine, (Biomedical Engineering, Cleveland Clinic)
Neural control of movement

Maciej Zborowski, PhD
(Polish Academy of Science)
Associate Professor, Molecular Medicine (Biomedical Engineering, Cleveland Clinic)
Membrane separation of blood proteins

Assem G. Ziady, PhD
(Case Western Reserve University)
Assistant Professor, Pediatrics, University Hospitals-Case Medical Center
Proteomics, DNA nanoparticles, mass spectrometry, cystic fibrosis, inflammation, and redox signaling

Nicholas P. Ziats, PhD
(Case Western Reserve University)
Associate Professor, Pathology, University Hospitals-Case Medical Center
Vascular grafts; vascular cells; blood vessels

Christian Zorman, PhD
(Case Western Reserve University)
Associate Professor, Electrical Engineering & Computer Science
Development of enabling materials for micro- and nanosystems

Research Appointments

Musa L. Audu, PhD
(Case Western Reserve University)
Research Associate Professor
Human musculoskeletal modeling and development of control systems for rehabilitation of individuals with balance disorders

Niloy Bhadra, MD, PhD
(Case Western Reserve University)
Research Assistant Professor
Experimental and computational studies of high frequency waveforms for reversible conduction block of peripheral nerves; design, testing and implementation of neuroprosthetic systems for the upper limb

Michael Jenkins, PhD
(Case Western Reserve University)
Research Assistant Professor
Biomedical optics; development of optical pacing and optical imaging technologies for investigating cardiac development and diseases

Nicola Lai, PhD
(University of Pisa, Pisa/Cagliari, Italy)
Research Assistant Professor
Systems biology investigation of muscle exercise metabolism in diabetes; systems integrated physiology; mass transport and metabolism in cell, tissue and organ systems; mathematical modeling and analysis of dynamic and distributed systems

Pallavi Tiwari, PhD
(Rutgers University)
Research Assistant Professor
Developing Image Analysis and Machine Learning Tools for Neuroimaging applications

Satish Viswanath, PhD
(Rutgers University)
Research Assistant Professor
Developing image analysis, machine learning, and computational modeling tools for diseases, such as disease detection, radiation therapy treatment, and focal laser ablation

Junmin Zhu, PhD
(Peking University)
Research Assistant Professor
Biomimetic engineering of nanomaterials; design and synthesis of extracellular matrix (ECM)-mimetic scaffolds for bioengineering vascular grafts and networks; engineering of multifunctional nanosystems for targeting tumor angiogenesis

Adjunct Faculty

Kath Bogie, D. Phil
(University of Oxford)
Adjunct Assistant Professor, Biomedical Engineering (VA Medical Center)
Wound prevention and treatment in individuals with paralysis and in the biomechanics of wheelchairs and seating for people with limited mobility

Scott Bruder, MD, PhD
(Case Western Reserve University)
Adjunct Professor
Advises MD/PhD students regarding careers in industry.

Richard C. Burgess, MD, PhD
(Case Western Reserve University)
Adjunct Professor of Biomedical Engineering (Neurological Computing, Cleveland Clinic)
Magnetoencephalography; Electrophysiological monitoring; EEG processing; medical informatics

J. Kevin Donahue, MD
(Washington University)
Adjunct Professor (University of Massachusetts)
Arrhythmia ablation; atrial fibrillation; cardiac arrhythmia; gene therapy; implantable cardioverter defibrillator; myocardial infarction; ventricular tachycardia

Alan F. Dowling, PhD
(Massachusetts Institute of Technology)
Adjunct Professor (Global Health Associates LLC)
Models of health care systems

Colin Drummond, PhD (Syracuse University), MBA (Case Western Reserve University)
Adjunct Assistant Professor
Sensor and information technology systems

William J. Dupps, MD, PhD
(The Ohio State University)
Adjunct Professor (Cole Eye Institute and Biomedical Engineering, Cleveland Clinic)
Application of engineering tools to the diagnosis and management of biomechanical disorders such as keratoconus and glaucoma

Luis Gonzalez-Reyes, MD (University of Los Andes), PhD (London University)
Adjunct Instructor, Biomedical Engineering
Physiology; biophysics; molecular and cellular physiology

Elizabeth C. Hardin, PhD
(University of Massachusetts)
Adjunct Assistant Professor of Biomedical Engineering, (VA Medical Center)
Neural prostheses and gait mechanics; improving gait performance with neural prostheses using strategies developed in conjunction with forward dynamics musculoskeletal models

Thomas Hering, PhD
(Case Western Reserve University)
Adjunct Associate Professor (Orthopaedic Surgery, Washington University)
Cartilage; extracellular matrix biochemistry and molecular biology; transcriptional regulation of chondrogenesis

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

Jill S. Kawalec-Carroll, PhD
(Case Western Reserve University)
Adjunct Assistant Professor, Biomedical Engineering, Research Director, Ohio College of Podiatric Medicine
Biomaterials and biomechanics of foot prostheses

Kevin L. Kilgore, PhD
(Case Western Reserve University)
Adjunct Assistant Professor, Biomedical Engineering, Orthopaedics, (MetroHealth Medical Center)
Functional electrical stimulation; neuroprostheses

William Landis, PhD
(Massachusetts Institute of Technology)
Adjunct Professor of Biomedical Engineering (Microbiology, Immunology and Biochemistry, University of Akron)
Mineralization of vertebrates, effect of mechanical force on mineralization, calcium transport in mineralization, tissue engineering

Paul Marasco, PhD
(Vanderbilt University)
Adjunct Assistant Professor
Neural Plasticity, Sensory Neurophysiology, Brain Organization, Sensory Integration with Prosthetic devices

Aaron S. Nelson, MD
(Medical College of Ohio)
Adjunct Assistant Professor, Medical Director, MIMvista Corporation (Cleveland, OH)
Multimodality and quantitative imaging for neurologic and cardiac disorders, oncology, and radiation oncology

Anand Ramamurthi, PhD
(Oklahoma State University)
Adjunct Associate Professor (Biomedical Engineering, Cleveland Clinic)
Artificial heart valves, tissue engineering, biomaterials, thrombosis

Michael Southworth
(Webster University)
Adjunct Instructor (Southworth and Associates LLC)
Regulatory affairs for biosciences

James Thomas, MD
(Harvard)
Adjunct Professor (Cardiovascular Medicine, Cleveland Clinic)
Ultrasound, ultrasonography, and digital echocardiography

Antonie Van den Bogert, PhD
(University of Utrecht)
Adjunct Associate Professor (Orchard Kinetics, LLC)
Biomechanics, motion capture, computational modeling

Franciscus Van der Helm, PhD
(Delft University)
Adjunct Professor (Mechanical and Biomechanical Engineering, Delft University)
Development of a biomechanical model of the shoulder and elbow; fundamental research in the control of human arm motions

Gabriela Voskerician, PhD
(Case Western Reserve University)
Adjunct Assistant Professor (Krikorjan, Inc.)
Remote health management

Courses

EBME 105. Introduction to Biomedical Engineering. 3 Units.

This course is intended to introduce Freshmen to a wide variety of biomedical engineering fields including: biomaterials, tissue engineering, drug delivery systems, biomedical imaging and processing, cardiac measurement and analysis, neural engineering, neuromuscular control, and systems biology. Topics span research, development, and design for diagnostic and therapeutic applications. Prereq: Freshman standing.

EBME 201. Physiology-Biophysics I. 3 Units.

This course (1) teaches cell physiology from an engineering perspective - basics covered include cell structures and functions, genes and protein synthesis, diffusion fundamentals, electrical properties of neural and muscle cells, sensory transduction, and integration of function on the micro and macro scale; (2) teaches how to use engineering tools to model different cell functions and predict, measure, and control cell behavior; (3) introduces mathematical and graphical analysis of specific physiological systems emphasizing applied modeling and simulation. Prereq: Must have declared major or minor in Biomedical Engineering, or requisites not met permission.

EBME 202. Physiology-Biophysics II. 3 Units.

This course is an extension of EBME 201 that will extend the application of system modeling and simulation to complex physiological systems in a clinical environment. The course will cover models of biochemical systems with pathology, muscle, the cardiovascular system, respiratory system, renal and hepatic systems with pathology and clinical applications. Prereq: EBME 201 or consent of instructor.

EBME 300. Dynamics of Biological Systems: A Quantitative Introduction to Biology. 3 Units.

This course will introduce students to dynamic biological phenomena, from the molecular to the population level, and models of these dynamical phenomena. It will describe a biological system, discuss how to model its dynamics, and experimentally evaluate the resulting models. Topics will include molecular dynamics of biological molecules, kinetics of cell metabolism and the cell cycle, biophysics of excitability, scaling laws for biological systems, biomechanics, and population dynamics. Mathematical tools for the analysis of dynamic biological processes will also be presented. Students will manipulate and analyze simulations of biological processes, and learn to formulate and analyze their own models. This course satisfies a laboratory requirement for the biology major. Offered as BIOL 300 and EBME 300.

EBME 303. Structure of Biological Materials. 3 Units.

Structure of proteins, nucleic acids, connective tissue and bone, from molecular to microscopic levels. An introduction to bioengineering biological materials and biomimetic materials, and an understanding of how different instruments may be used for imaging, identification and characterization of biological materials. Offered as: EBME 303 and EMAC 303. Recommended preparation: EBME 201, EMBE 202, and EMAC 270.

EBME 305. Materials for Prosthetics and Orthotics. 3 Units.

A synthesis of skeletal tissue structure and biology, materials engineering, and strength of materials concepts. This course is centered on deepening the concept of biocompatibility and using it to pose and solve biomaterials problems. We cover: fundamental concepts of materials used for load bearing medical applications, wear, corrosion, and failure of implants. Structure and properties of hard tissues and joints are presented using a size hierarchy motif. Tools and analysis paradigms useful in the characterization of biomaterials are covered in the context of orthopedic and dental applications. Prereq: EBME 306.

EBME 306. Introduction to Biomedical Materials. 3 Units.

Biomaterials design and application in different tissue and organ systems. The relationship between the physical and chemical structure of biomaterials, functional properties, and biological response. Recommended preparation: EBME 201 and EBME 202.

EBME 307. Biomechanical Prosthetic Systems. 3 Units.

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. Recommended preparation: Consent of instructor and senior standing.

EBME 308. Biomedical Signals and Systems. 3 Units.

Quantitative analysis of biomedical signals and physiological systems. Time domain and frequency domain analysis of linear systems. Fourier and Laplace transforms. A/D conversion and sampling. Filter design. Computational laboratory experiences with biomedical applications. Prereq: EBME 201, EBME 202, MATH 224 and ENGR 210. Coreq: EBME 358.

EBME 309. Modeling of Biomedical Systems. 3 Units.

Mathematical modeling of biomedical systems. Lumped and distributed models of electrical, mechanical, and chemical processes applied to cells, tissues, and organ systems. Numerical methods for solving equations to simulate system models. Recommended preparation: EBME 308. Coreq: EBME 359.

EBME 310. Principles of Biomedical Instrumentation. 3 Units.

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. Recommended preparation: EBME 308. Coreq: EBME 360.

EBME 315. Applied Tissue Engineering. 3 Units.

This course is designed to provide students with understanding and expertise of the basic tools in tissue engineering research. Through lectures the students will be introduced to the array of methods and materials available to tissue engineering researchers, learn how to rationally determine suitable choices for their applications, and receive instruction on how to implement those designs. Much of the course will be spent in the BME Tissue Engineering Laboratory getting hands-on experience (1) on the materials end with materials selection, characterization, and scaffold fabrication; (2) on the cell end with cell culture, tissue characterization and bioreactor design. The class will be assessed by a weekly grading of the students' lab notebooks, as well as a final exam based on the content learned throughout the semester.

EBME 316. Biomaterials for Drug Delivery. 3 Units.

The teaching objective is to provide students with a basic understanding of the principles of design and engineering of well-defined molecular structures and architectures intended for applications in controlled release and organ-targeted drug delivery. The course will discuss the therapeutic basic of drug delivery based on drug pharmacodynamics and clinical pharmacokinetics. Biomaterials with specialized structural and interfacial properties will be introduced to achieve drug targeting and controlled release. Offered as EBME 316 and EBME 416. Prereq: EBME 306 and PHRM 309

EBME 317. Excitable Cells: Molecular Mechanisms. 3 Units.

Ion channels are the molecular basis of membrane excitability in all cell types, including neural, 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. Graduate students will present exemplary papers in the journal club style. Recommended preparation: EBME 201 or equivalent. Offered as EBME 317 and EBME 417.

EBME 318. Biomedical Engineering Laboratory I. 1 Unit.

Experiments for measurement, assisting, replacement, or control of various biomedical systems. Students choose a few lab experiences from a large number of offerings relevant to all BME sequences. Experiments are conducted primarily in faculty labs with 3-8 students participating. Recommended preparation: ENGR 210. Prereq: BME Major, EBME 201, EBME 202 and Prereq or Coreq: EBME 308.

EBME 319. Biomedical Engineering Laboratory II. 1 Unit.

Experiments for measurement, assisting, replacement, or control of various biomedical systems. Students choose a few lab experiences from a large number of offerings relevant to all BME sequences. Experiments are conducted primarily in faculty labs with 3-8 students participating. Recommended preparation: EBME 201, EBME 202, and ENGR 210. Prereq or Coreq: EBME 318.

EBME 320. Medical Imaging Fundamentals. 3 Units.

General principles, instrumentation, and biomedical applications of medical imaging. Topics include: x-ray, ultrasound, MRI, nuclear imaging, image reconstruction, and image quality. Recommended preparation: EBME 308, ENGR 210, and EBME 202 or equivalent.

EBME 322. Applications of Biomedical Imaging. 3 Units.

This course will provide an introduction to biomedical imaging and its applications in measurements of physiological function, stem cell biology, and drug delivery. Students will learn about imaging technologies including basic principles of imaging (resolution and contrast), optical microscopy and in vivo imaging, and magnetic resonance imaging. Emerging techniques in cellular and molecular imaging, including targeted imaging agents and reporter gene imaging will be discussed. Biomedical applications will include such topics as tumor characterization in drug assessment, functional brain mapping, targeted drug delivery, functional cardiovascular measurements, and stem cell research will be demonstrated. Prereq: EBME 201, EBME 202, EBME 308, PHYS 121, PHYS 122.

EBME 325. Introduction to Tissue Engineering. 3 Units.

The goal of this course is to present students with a firm understanding of the primary components, design principles, and engineering concepts central to the field of tissue engineering. First, the biological principles of tissue formation during morphogenesis and wound repair will be examined. The cellular processes underlying these events will be presented with an emphasis on microenvironment regulation of cell behavior. Biomimetic approaches to controlling cell function and tissue formation via the development of biomaterial systems will then be investigated. Case studies of regeneration strategies for specific tissues will be presented in order to examine the different tissue-specific engineering strategies that may be employed. Special current topics in tissue engineering will also be covered. Recommended preparation: EBME 306, BIOL 362, and CHEM 223.

EBME 327. Bioelectric Engineering. 3 Units.

Quantitative bioelectricity: action potentials and cable equations. Origins of biopotentials, biopotential recording, electrical stimulation of excitable tissue, electrodes/electrochemistry and cardiac electrophysiology. Overview of major biomedical devices. Recommended preparation: EBME 201, EBME 317 and ENGR 210.

EBME 328. Biomedical Engineering R&D Training I. 1 Unit.

This course will provide research and development in the laboratory of a mentoring faculty member. Varied R&D experiences will include activities in biomedical instrumentation, tissue engineering, imaging, drug delivery, and neural engineering. Each Student must identify a faculty mentor, and together they will create description of the training experience prior to the first class. Prereq: EBME 201 and EBME 202.

EBME 329. Biomedical Engineering R&D Training II. 1 Unit.

This course will provide research and development training in the laboratory of a mentoring faculty member. Varied R&D experiences will include activities in biomedical instrumentation, tissue engineering, imaging, drug delivery, and neural engineering. Each student must identify a faculty mentor, and together will create a description of the training experience prior to the first class. Recommended preparation EBME 328. Prereq: EBME 201 and EBME 202.

EBME 350. Quantitative Molecular, Cellular and Tissue Bioengineering. 3 Units.

Physical and chemical principles associated with kinetics and mass transport. Molecular-cellular components incorporated in quantitative analysis of cellular, tissue, and organ systems. Mathematical and computational modeling developed for diagnostic and therapeutic applications. Offered as EBME 350 and ECHE 355. Prereq: EBME 309

EBME 358. Biomedical Signals and Systems Laboratory. 1 Unit.

Computational laboratory experiences with biomedical applications. Numerical methods with MATLAB applications in biomedical engineering. Prereq: EBME 201, EBME 202, MATH 224 and ENGR 210. Coreq: EBME 308.

EBME 359. Biomedical Computer Simulation Laboratory. 1 Unit.

Computer simulation of mathematical models of biomedical systems. Numerical methods with MATLAB applications. Coreq: EBME 309.

EBME 360. Biomedical Instrumentation Laboratory. 1 Unit.

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 361. Biomedical Image Processing and Analysis. 3 Units.

Principles of image processing and analysis with applications to clinical and biomedical research. Topics include image filtering, registration, morphological processing, segmentation, classification, and 3D image visualization. There will be interesting, realistic computer projects in Matlab. Offered as EBME 361 and EBME 461. Prereq: EBME 308.

EBME 370. Principles of Biomedical Engineering Design. 2 Units.

Students learn and implement the design process to produce working prototypes of medical devices with potential commercial value to meet significant clinical needs. Critical examination of contemporary medical problems is used to develop a specific problem statement. The class is divided into teams of 3 to 4 students. Each team integrates their knowledge and skills to design a device to meet their clinical need. Project planning and management, including resource allocation, milestones, and documentation, are required to ensure successful completion of projects within the allotted time and budget. Formal design reviews by a panel of advisors and outside medical device experts are required every four weeks. Every student is required to give oral presentations at each formal review and is responsible for formal documentation of the design process, resulting in an executive summary and complete design history file of the project. The course culminates with a public presentation of the team's device to a panel of experts. This course is expected to provide the student with a real-world, capstone design experience. Recommended preparation: EBME 310

EBME 380. Biomedical Engineering Design Experience. 3 Units.

This course is the culmination of the BME educational experience in which the student will apply acquired skills and knowledge to create a working device or product to meet a medical need. Students will learn how to apply engineering skills to solve problems and physically realize a project design. The course structure includes regular meetings with a faculty project advisor, regular reports of accomplished activity, hands on fabrication of devices, and several lectures from leading engineers from industry and academia that have first hand experience in applying the principles of design to Biomedical Engineering. Students will also provide periodic oral progress reports and a final oral presentation with a written design report. Counts as SAGES Senior Capstone. Prereq: EBME 370.

EBME 396. Special Topics in Undergraduate Biomedical Engineering I. 1 - 18 Unit.

(Credit as arranged.)

EBME 398. Senior Project Laboratory I. 3 Units.

The design process required to produce biomedical devices, research equipment, and clinical tools is developed. Topics include identification of need; requirements specification; project management; working in teams; solutions conceptualization, refinement, and selection; hazard and risk analysis and mitigation; verification; validation; regulatory requirements; and medical device pathways to the market. Through critical examination of contemporary medical research and clinical problems, students, working in teams, will identify a need to develop a specific problem statement, project plan, input requirements, solution concept and risk analysis. Students will provide periodic oral progress reports and a final oral presentation with a written design report. Recommended preparation: EBME 310. Counts as SAGES Senior Capstone.

EBME 399. Senior Project Laboratory II. 3 Units.

Continuation of EBME 398. Recommended preparation: EBME 398 and consent of department. Counts as SAGES Senior Capstone.

EBME 400T. Graduate Teaching I. 0 Units.

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. Recommended preparation: UNIV 400, BME Ph.D. student.

EBME 401. Biomedical Instrumentation and Signal Analysis. 4 Units.

Graduate students with various undergraduate backgrounds will learn the fundamental principles of biomedical measurements that integrate instrumentation and signal processing with problem-based hands-on experience. Prereq or Coreq: May not have taken EBME 401 prior to Fall 2011 or EBME 421 after Summer 2011.

EBME 402. Organ/Tissue Physiology and Systems Modeling. 4 Units.

Graduate students with various undergraduate backgrounds will learn the fundamental principles of organ and tissue physiology as well as systems modeling. Prereq or Coreq: May not have taken EBME 402 prior to Fall 2011 or EBME 422 after Summer 2011.

EBME 403. Biomedical Instrumentation. 3 Units.

Analysis and design of biomedical instruments with special emphasis on transducers. Body, system, organ, tissue, cellular, molecular, and nano-level measurements. Applications to clinical problems and biomedical research. Prereq: Graduate standing.

EBME 406. Polymers in Medicine. 3 Units.

This course covers the important fundamentals and applications of polymers in medicine, and consists of three major components: (i) the blood and soft-tissue reactions to polymer implants; (ii) the structure, characterization and modification of biomedical polymers; and (iii) the application of polymers in a broad range of cardiovascular and extravascular devices. The chemical and physical characteristics of biomedical polymers and the properties required to meet the needs of the intended biological function will be presented. Clinical evaluation, including recent advances and current problems associated with different polymer implants. Recommended preparation: EBME 306 or equivalent. Offered as EBME 406 and EMAC 471. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 407. Neural Interfacing. 3 Units.

Neural interfacing refers to the principles, methods, and devices that bridge the boundary between engineered devices and the nervous system. It includes the methods and mechanisms to get information efficiently and effectively into and out of the nervous system to analyze and control its function. This course examines advanced engineering, neurobiology, neurophysiology, and the interaction between all of them to develop methods of connecting to the nervous system. The course builds on a sound background in Bioelectric Phenomenon to explore fundamental principles of recording and simulation, electrochemistry of electrodes in biological tissue, tissue damage generated by electrical stimulation, materials and material properties, and molecular functionalization of devices for interfacing with the nervous system. Several examples of the state-of-art neural interfaces will be analyzed and discussed. Recommended preparation: EBME 401. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 408. Engineering Tissues/Materials - Learning from Nature's Paradigms. 3 Units.

This course aims to provide students with a foundation based on "nature's" design and optimization" criteria for engineering tissues and biomaterials. This will be achieved through focused review of the principles of development, wound healing, regeneration, and repair through remodeling, using nature as a paradigm. Principles of transport will be explored quantitatively and in relation to multi-organismal evolution. Cellular engineering principles will be explored, including current state of the art in stem cell physiology and therapeutic applications. Endogenous engineering approaches to surgical tissue reconstruction will be analyzed. An overview of contemporary approaches to tissue and cell engineering will be given, including tissue scaffold design, use of bioreactors in tissue engineering, and molecular surface modifications for integration of engineered tissues in situ. Fundamental engineering principles will be augmented through case studies involving specific applications. Ethical considerations related to clinical non-clinical application of tissue and cell engineering technology will be integrated into each lecture. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 409. Systems and Signals in Biomedical Engineering. 3 Units.

Modeling and analysis of dynamic systems. Processing and analysis of signals and images in time and frequency domains. Spatially lumped and distributed linear and nonlinear models. Feedback systems. Optimal parameter estimation. Matrix methods. Initial-and boundary-value problems. Laplace and Fourier transforms. Spectral analysis. Sampling. Filtering. Biomedical applications include enzyme kinetics, hemodialysis, respiratory control, drug delivery, and cell migration. Numerical methods using MATLAB. Prereq: EBME 308 and EBME 309 or equivalent.

EBME 410. Medical Imaging Fundamentals. 3 Units.

Physical principles of medical imaging. Imaging devices for x-ray, ultrasound, magnetic resonance, etc. Image quality descriptions. Patient risk. Recommended preparation: EBME 308 and EBME 310 or equivalent. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 416. Biomaterials for Drug Delivery. 3 Units.

The teaching objective is to provide students with a basic understanding of the principles of design and engineering of well-defined molecular structures and architectures intended for applications in controlled release and organ-targeted drug delivery. The course will discuss the therapeutic basic of drug delivery based on drug pharmacodynamics and clinical pharmacokinetics. Biomaterials with specialized structural and interfacial properties will be introduced to achieve drug targeting and controlled release. Offered as EBME 316 and EBME 416. Prereq: EBME 306 and PHRM 309 or graduate standing.

EBME 417. Excitable Cells: Molecular Mechanisms. 3 Units.

Ion channels are the molecular basis of membrane excitability in all cell types, including neural, 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. Graduate students will present exemplary papers in the journal club style. Recommended preparation: EBME 201 or equivalent. Offered as EBME 317 and EBME 417. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 418. Electronics for Biomedical Engineering. 3 Units.

Fundamental concepts of analog design with special emphasis on circuits for biomedical applications. Analysis and design of discrete and integrated circuit amplifiers; application circuits of operational amplifiers; noise measurement; communication circuits; specialized biomedical applications such as circuits for low noise amplification, high CMRR biomedical amplifiers, implantable circuits, circuits for electrochemistry and circuits for optical recordings, circuits for recording neural activity, electrical safety and telemetry. A team project will be required for all students. Recommended preparation: EECS 344 or consent of instructor. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 419. Applied Probability and Stochastic Processes for Biology. 3 Units.

Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using both MATLAB and the R statistical package. Student projects will comprise a major part of the course. Offered as BIOL 319, EECS 319, MATH 319, BIOL 419, EBME 419, and PHOL 419.

EBME 420. Biomedical Ultrasound Technologies. 3 Units.

Biomedical ultrasound technologies including both ultrasound for imaging and as a therapeutic tool. Fundamentals of ultrasound physics, instrumentation, and imaging. Novel imaging techniques with high resolution ultrasound. Ultrasound contrast agents for in vivo targeted imaging. Biomedical effects on cells and tissues. High intensity focused ultrasound for tumor ablation. Ultrasound mediated targeted intracellular drug/gene delivery.

EBME 421. Bioelectric Phenomena. 3 Units.

The goal of this course is to provide working knowledge of the theoretical methods that are used in the fields of electrophysiology and bioelectricity for both neural and cardiac systems. These methods will be applied to describe, from a theoretical and quantitative perspective, the electrical behavior of excitable cells, the methods for recording their activity and the effect of applied electrical and magnetic fields on excitable issues. A team modeling project will be required. Recommended preparation: differential equations, circuits. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 422. Muscles, Biomechanics, and Control of Movement. 4 Units.

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. Recommended preparation: EMAE 181 or equivalent. Offered as EBME 422 and EMAE 402. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 425. Tissue Engineering and Regenerative Medicine. 3 Units.

This course will provide advanced coverage of tissue engineering with a focus on stem cell-based research and therapies. Course topics of note include stem cell biology and its role in development, modeling of stem cell function, controlling stem cell behavior by engineering materials and their microenvironment, stem cells' trophic character, and state-of-the-art stem cell implementation in tissue engineering and other therapeutic strategies. Offered as EBME 425 and PATH 435. Prereq: EBME 325 or equivalent or graduate standing.

EBME 426. Nanomedicine. 3 Units.

Principles of the design and application of nanomedicine, including nanosized drug delivery systems, protein delivery systems, gene delivery systems and imaging probes. Methods for bioconjugation and surface modifications. Structure property relationships of nanosized biomaterials. In vivo and intracellular transport, pharmacokinetics, biodistribution, drug release kinetics, and biocompatibility of various nanosized therapeutics and diagnostics. Theranostics, image-guided drug delivery and therapy. Prereq: EBME 316 or EBME 416 or requisites not met permission

EBME 427. Movement Biomechanics and Rehabilitation. 3 Units.

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. Recommended preparation: Consent of instructor and graduate standing. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 431. Physics of Imaging. 3 Units.

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. Recommended preparation: PHYS 122 or PHYS 124 or EBME 410. Offered as EBME 431 and PHYS 431.

EBME 440. Translational Research for Biomedical Engineers. 3 Units.

Translation of laboratory developments to improve biomedical and clinical research and patient care. Interdisciplinary and team communication. Evaluation of technology and research planning with clinical and engineering perspectives. Discussing clinical situations, shadowing clinicians, attending Grand Rounds and Morbidity-Mortality conferences. Validation study design. Regulatory/oversight organization. Protocol design and informed consent for Institutional Review Board (IRB) approval. NIH requirements for human subject research. Special project reports to produce IRB protocol or NIH-style proposal. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 447A. Rehabilitation for Scientists and Engineers. 0 Units.

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 re-entry.

EBME 447B. Rehabilitation for Scientists and Engineers. 3 Units.

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 re-entry. Coreq: EBME 447A.

EBME 451. Molecular and Cellular Physiology. 3 Units.

This course covers cellular and molecular basics for graduate students with little or no prior biology background. The emphasis of EBME 451 is on the molecular and cellular mechanisms underlying physiological processes. Structure-function relationship will be addressed throughout the course. The primary goal of the course is to develop understanding of the principles of the physiological processes at molecular and cellular level and to promote independent thinking and ability to solve unfamiliar problems. This course is no longer a core course of the Biomedical Engineering graduate curriculum but serves as a fundamentals course to prepare students for the graduate cellular and molecular physiology core. Prereq: Graduate standing.

EBME 452. Tissue and Organ Systems Physiology. 3 Units.

Mechanisms of membrane and capillary-tissue transport, tissue mechanics, electrical propagation, signaling, control and regulation processes. Cardiac vascular, renal, respiratory, gastro-intestinal, neural, sensory, motor, musculoskeletal, and skeletal systems. Basic engineering analysis for quantitative understanding of physiological concepts. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 460. Advanced Topics in NMR Imaging. 3 Units.

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. Recommended preparation: EBME 431 or PHYS 431. Offered as EBME 460 and PHYS 460. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 461. Biomedical Image Processing and Analysis. 3 Units.

Principles of image processing and analysis with applications to clinical and biomedical research. Topics include image filtering, registration, morphological processing, segmentation, classification, and 3D image visualization. There will be interesting, realistic computer projects in Matlab. Offered as EBME 361 and EBME 461. Prereq: EBME 401.

EBME 462. Cellular and Molecular Imaging. 3 Units.

Frontier issues in biomedical imaging that address problems at the cellular and molecular levels. Topics include endogenous methods to assess molecular compositions, imaging agents, reporter genes and proteins, and drug delivery, which will be discussed in the context of applications in cancer, cardiology, central nervous system, ophthalmology, musculoskeletal diseases, pulmonary diseases, and metabolic diseases. Emphasis is placed on an interdisciplinary problem-based approach to investigate the application of biomedical imaging to biological and disease areas. Recommended preparation: EBME 410 and EBME 451 or consent of instructor. Prereq: Graduate standing or Undergraduate with Junior or Senior standing and a cumulative GPA of 3.2 or above.

EBME 467. Commercialization and Intellectual Property Management. 4 Units.

This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two laws students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 367, GENE 467, EBME 467 and EECS 467.

EBME 472. BioDesign. 3 Units.

Medical device innovations that would have been considered science fiction a decade ago are already producing new standards of patient care. Innovation leading to lower cost of care, minimally invasive procedures and shorter recovery times is equally important to healthcare business leaders, educators, clinicians, and policy-makers. Innovation is a driver of regional economic development and wealth creation in organizational units ranging in size from the start-up to the Fortune 500 companies. In a broader context, the pace of translational research leading to product and service innovation is highly interdisciplinary, thus, new products and services result from team efforts, marked by a systematic, structured approach to bringing new medical technologies to market and impacting patient care. In this course we examine medical technology innovations in the context of (A) addressing unmet clinical needs, (B) the process of inventing new medical devices and instruments, and (C) subsequent implementation of these advances in patient care. In short, the student learns the process of "identify, invent, implement" in the field of BioDesign. Offered as EBME 472, IIME 472 and SYBB 472.

EBME 473. Fundamentals of Clinical Information Systems. 3 Units.

Technology has played a significant role in the evolution of medical science and treatment. While we often think about progress in terms of the practical application of, say, imaging to the diagnosis and monitoring of disease, technology is increasingly expected to improve the organization and delivery of healthcare services, too. Information technology plays a key role in the transformation of administrative support systems (finance and administration), clinical information systems (information to support patient care), and decision support systems (managerial decision-making). This introductory graduate course provides the student with the opportunity to gain insight and situational experience with clinical information systems (CIS). Often considered synonymous with electronic medical records, the "art" of CIS more fundamentally examines the effective use of data and information technology to assist in the migration away from paper-based systems and improve organizational performance. In this course we examine clinical information systems in the context of (A) operational and strategic information needs, (B) information technology and analytic tools for workflow design, and (C) subsequent implementation of clinical information systems in patient care. Legal and ethical issues are explored. The student learns the process of "plan, design, implement" through hands-on applications to select CIS problems, while at the same time gaining insights and understanding of the impacts placed on patients and health care providers. Offered as EBME 473 and IIME 473.

EBME 474. Biotransport Processes. 3 Units.

Biomedical mass transport and chemical reaction processes. Basic mechanisms and mathematical models based on thermodynamics, mass and momentum conservation. Analytical and numerical methods to simulate in vivo processes as well as to develop diagnostic and therapeutic methods. Applications include transport across membranes, transport in blood, tumor processes, bioreactors, cell differentiation, chemotaxis, drug delivery systems, tissue engineering processes. Recommended preparation: EBME 350 and EBME 409 or equivalent. Offered as EBME474 and ECHE 474. Prereq: EBME 409 and graduate standing or EBME 309 and senior standing.

EBME 478. Computational Neuroscience. 3 Units.

Computer simulations and mathematical analysis 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 learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, EBME 478, EECS 478, MATH 478 and NEUR 478.

EBME 480A. Introduction to Wireless Health. 3 Units.

Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as EECS 480A and EBME 480A.

EBME 480B. The Human Body. 3 Units.

Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as EECS 480B and EBME 480B.

EBME 480C. Biomedical Sensing Instrumentation. 3 Units.

Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as EECS 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

EBME 480D. The Health Care Delivery Ecosystem. 3 Units.

Health care delivery across the continuum of care in the United States, including health policy and reform, financing of care, comparative health systems, population health, public health, access to care, care models, cost and value, comparative effectiveness, governance, management, accountability, workforce, and the future. Discussions of opportunities and challenges for wireless health, integrated into the foregoing topics. Perspective on health care delivery in other countries. Offered as EECS 480D and EBME 480D.

EBME 480E. Wireless Communications and Networking. 3 Units.

Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as EECS 480E and EBME 480E.

EBME 480F. Physicians, Hospitals and Clinics. 3 Units.

Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as EECS 480F and EBME 480F.

EBME 480M. Introduction to Medical Informatics. 3 Units.

Current state and emerging trends in Medical Informatics (MI) and associated health information systems. Principles, data, data management, system interoperability, patient privacy, information security, electronic records, telehealth, regulatory issues, clinical decision support, mobile documentation, devices and wireless communications in healthcare. Impact of wireless technology on emerging health information systems and processes. Offered as EECS 480M and EBME 480M.

EBME 480N. Introduction to Health Decision and Knowledge Support Systems. 3 Units.

Current state and emerging trends in use of decision support systems (DSS) and knowledge support systems (KSS) in health care delivery. Information, knowledge and decision principles; Health data; Clinical decision and knowledge support, DSS/KSS development and adoption, and regulatory issues. Impact of wireless technology on emerging DSS and KSS, and related processes. Offered as EBME 480N and EBME 480N

EBME 480O. Introduction to Health Information Technology Implementation. 3 Units.

Current state and emerging trends in the implementation and adoption of health information technology (HIT). Macroergonomics; Technology transfer and adoption; Systems adoption life cycle; Impact of regulation; Decision and work transformation; HIT specification and acquisition; Contracting issues; Implementation, use, and evaluation; Impact of wireless technology on emerging processes. Offered as EECS 480O and EBME 480O. Prereq: EBME 480M.

EBME 480P. Advanced Biomedical Instrumentation. 3 Units.

Analysis and design of biosensors in the context of biomedical measurements. Base sensors using electrochemical, optical, piezoelectric, and other principles. Binding equilibria, enzyme kinetics, and mass transport modalities. Adding the "bio" element to base sensors and mathematical aspects of data evaluation. Applications to clinical problems and biomedical research. Offered as EECS 480P and EBME 480P.

EBME 480Q. Regulatory Policy and Regulations. 3 Units.

Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the House of Representatives and its committees; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/FDA MoU; CMS and Reimbursement; privacy and security. Offered as EECS 480Q and EBME 480Q.

EBME 480R. User Experience Engineering. 3 Units.

Social, cognitive, behavioral, and contextual elements in the design of healthcare technology and systems. User-centered design paradigm from a broad perspective, exploring dimensions of product user experience and learning to assess and modify the design of healthcare technology. Practical utilization of user centered design method and assessment techniques for approaching a design problem. Offered as EECS 480R and EBME 480R.

EBME 480S. Wireless Health Product Development. 3 Units.

Integrating application requirements, market data, concept formulation, design innovation, and manufacturing resources for creating differentiated wireless health products that delight the user. Learning user-centric product development best practices, safety, security and privacy considerations, and risk management planning. Understanding the regulatory process. Identifying and managing product development tradeoffs. Offered as EECS 480S and EBME 480S. Prereq: EBME 480R.

EBME 500T. Graduate Teaching II. 0 Units.

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 students. Recommended preparation: EBME 400T, BME Ph.D. student.

EBME 507. Motor System Neuroprostheses. 3 Units.

Fundamentals of neural stimulation and sensing, neurophysiology and pathophysiology of common neurological disorders, general implantation and clinical deployment issues. Specialist discussions in many application areas such as motor prostheses for spinal cord injury and stroke, cochlear implants, bladder control, stimulation for pain management, deep brain stimulation, and brain computer interfacing. Prereq: Graduate standing.

EBME 513. Biomedical Optical Diagnostics. 3 Units.

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. Recommended preparation: EBME 403 or PHYS 326 or consent. Prereq: Graduate standing.

EBME 519. Parameter Estimation for Biomedical Systems. 3 Units.

Linear and nonlinear parameter estimation of static and dynamic models. Identifiability and parameter sensitivity analysis. Statistical and optimization methods. Design of optimal experiments. Applications include control of breathing, iron kinetics, ligand-receptor models, drug delivery, tumor ablation, tissue responses to heating. Critical analysis of journal articles. Simulation projects related to student research. Recommended preparation: EBME 409. Prereq: Graduate standing.

EBME 570. Graduate Professional Development for Biomedical Engineers. 1 Unit.

Students will be trained in topics including public speaking, grant writing, notebook management, professionalism, etc. Prereq: Graduate standing.

EBME 600T. Graduate Teaching III. 0 Units.

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 students. Recommended preparation: EBME 500T, BME Ph.D. student.

EBME 601. Research Projects. 1 - 18 Unit.**EBME 602. Special Topics. 1 - 18 Unit.****EBME 607. Neural Engineering Topics. 1 Unit.**

The goal of this class is to explore topics in Neural Engineering not covered in the curriculum. A single topic will be chosen per semester. Four speakers with expertise in the chosen area will be invited to the campus. Each speaker will give a seminar and participate in a 2-hour workshop/journal club on the specific topic. The students will be assigned one or two seminal papers written by the speaker prior to the visit. Students will take turns presenting these papers to the rest of the class. The paper and the topic will then be open for discussion. At the end of the semester, the students will collaborate to write a single review article in a publishable format on the topic of the semester.

EBME 611. BME Departmental Seminar I. 0.5 Units.

Lectures by invited speakers on subjects of current interest in biomedical engineering. Students will be evaluated on reading and preparation of questions for select speakers, as well as weekly participation. Between this course and EBME 612 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters.

EBME 612. BME Departmental Seminar II. 0.5 Units.

Lectures by invited speakers on subjects of current interest in biomedical engineering. Students will be evaluated on reading and preparation of questions for select speakers, as well as weekly participation. Between this course and EBME 611 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters.

EBME 613. Topic Seminars for NeuroEngineering Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in NeuroEngineering. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 614 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 614. Topic Seminars for NeuroEngineering Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in NeuroEngineering. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 613 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 615. Topic Seminars for Imaging Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Imaging. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 616 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 616. Topic Seminars for Imaging Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Imaging. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 615 students must earn a minimum of 1 credit (2 semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 617. Topic Seminars for Biomaterials Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 618 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 618. Topic Seminars for Biomaterials Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 617 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 619. Topic Seminars for Miscellaneous Biomedical Engineering Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students in outside of NeuroEngineering, Imaging, and Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 620 students must earn a minimum of 1 credit (two semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 620. Topic Seminars for Miscellaneous Biomedical Engineering Students. 0.5 Units.

Lectures by students in the seminar series on subjects of current interest to biomedical engineering students on topics outside of NeuroEngineering, Imaging, and Biomaterials. Students will be evaluated on presentation preparation and performance, as well as weekly participation. Between this course and EBME 619 students must earn a minimum of 1 credit (2 semesters) and can take up to 4 credits over eight different semesters. Prereq: Graduate standing.

EBME 621. BME Research Rotation I. 0 Units.

Opportunity for trainees to participate in BME research under supervision of faculty.

EBME 651. Thesis M.S.. 1 - 18 Unit.**EBME 701. Dissertation Ph.D.. 1 - 18 Unit.**

Ph.D. candidates only. Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Chemical and Biomolecular Engineering

The Department of Chemical and Biomolecular Engineering 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 elective sequences in biochemical engineering, biomedical engineering, computing, energy, 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. A special biochemical engineering track is available, where students integrate biochemistry, biology, and bioengineering courses into the standard chemical engineering curriculum. Chemical and Biomolecular 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 eleven full-time faculty members, all of whom are pursuing active research programs. The research of the faculty is aimed at advanced and emerging areas of chemical engineering.

Mission

The chemical engineering department seeks to provide the expertise, environment, facilities, and administrative structure that inspire learning and the pursuit of scholarly activities in chemical engineering and related science and engineering disciplines. The Department will provide an educational program and research environment that will permit our graduates to compete in the evolving workplace, to permit students and faculty to advance knowledge at the highest levels of the profession, and to address the technological and personnel needs of industry, governments, and society.

Background

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, or law (mainly for patent law).

Research

Research in the department is sponsored by a variety of state and federal agencies, by private industry, and by foundations. Current active research topics include:

Energy Conversion and Storage

- Fuel cells
- Batteries
- Supercapacitors
- Transport/structure properties of polymer electrolytes for fuel cell applications
- Electrocatalysis
- Photovoltaics

Electrochemical Processes and Devices

- Electrodeposition
- Electrochemical sensors
- Implantable electrochemical devices
- Electrochemical reactor design
- Electrode processes
- Metallization of semiconductor devices by plating
- Electrometallurgy

Biomedical Applications of Chemical Engineering

- Cell/cellular transport processes in inflammation
- Tissue engineering
- Wound healing
- Neurosensing and neural stimulation
- Engineering of surfaces for sensing applications
- Implantable electrochemical devices
- BioMEMS and biosensors
- Dental implants
- Drug delivery

Diamond and Diamond-like Materials

- Chemical vapor deposition of diamond
- Electrochemistry on diamond
- Conductive diamond films

Design and Synthesis of Advanced Materials

- Growth of single-crystal Group III nitrides
- Plasma and plasma processing
- Nanoparticles, nanotubes, nanowires
- Molecular electronics Electrochemical synthesis of alloys and compounds

- Microvascular constructs
- Functional polymers and composites

Processing and Characterization of Novel Materials

- Nanomaterials and polymer nanocomposites
- Development of responsive additives for particle clusters
- Electronic materials
- Surface and colloidal phenomena
- Surfactant and polymer solutions
- NMR spectroscopy and imaging
- Light scattering/spectroscopy

Advanced Separation Methods

- Enhanced oil recovery
- Ultrasonically assisted sorting and collection of small particles
- Haemodialysis
- Electrochemical and membrane separations
- Nanoporous materials

Simulation and Modeling

- Mathematical modeling of engineering processes
- Molecular simulation, statistical mechanics
- Triboelectric charging
- Light scattering and laser anemometry
- Data acquisition, statistical analyses
- Current distributions/electrochemical systems
- Redox equilibria
- Biomimetics
- Monolayer dynamics
- Stochastic processes
- Electrode structures

Major (p. 39) | Concentrations and Elective Sequences (p. 39) | BS/MS (p. 42) | Minor (p. 42)

Undergraduate Programs

The Bachelor of Science degree program in Chemical Engineering is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

Program Educational Objectives

The undergraduate program in chemical engineering seeks to produce graduates who will:

1. apply the knowledge and skills acquired through the chemical engineering curriculum to their professional careers
2. assume positions of responsibility and/or leadership in industry, government, and business
3. pursue professional careers across a broad range of industries
4. succeed in post-graduate and professional degree programs

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Chemical Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multidisciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Bachelor of Science in Engineering

Required Courses: Major in Chemical Engineering

Major Required Courses

ECHE 151	Introduction to Chemical Engineering at Case	1
ECHE 260	Introduction to Chemical Systems	3
ECHE 360	Transport Phenomena for Chemical Systems	4
ECHE 361	Separation Processes	3
ECHE 362	Chemical Engineering Laboratory	4
ECHE 363	Thermodynamics of Chemical Systems	3
ECHE 364	Chemical Reaction Processes	3
ECHE 365	Measurements Laboratory	3
ECHE 367	Process Control	4
ECHE 398	Process Analysis and Design	3
ECHE 399	Chemical Engineering Design Project	3

Related Required Courses

CHEM 223 or CHEM 323	Introductory Organic Chemistry I Organic Chemistry I	3
CHEM 290	Chemical Laboratory Methods for Engineers	3
CHEM 336	Physical Chemistry II	3
STAT 313	Statistics for Experimenters	3
Materials Elective: one of the following courses:		3
EMAC 270	Introduction to Polymer Science and Engineering	
EMAC 276	Polymer Properties and Design	
EMSE 343	Materials for Electronics and Photonics	

Approved Breadth Elective Sequence	9-11
Total Units	58-60

Concentrations and Breadth 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. Eleven elective sequences have standing departmental approval: biochemical engineering, biomedical engineering, computing, electrochemical engineering, electronic materials, energy, environmental engineering, management/entrepreneurship, polymer science, undergraduate research and systems and control. There is also an advanced study sequence for students in the combined BS/MS program. Subject to departmental approval, students may alternatively choose to design their own breadth elective sequence.

In addition, two concentrations, one in biochemical engineering and the second in pre-medical studies, are available for students interested in these paths.

Biochemical Engineering Concentration

Biochemical engineering can be defined as the field of application of chemical engineering principles to systems that utilize biomolecules or bio-organisms to bring forth biotransformation. Biochemical engineering applications are versatile, ranging from waste-water treatment to production of therapeutic proteins. For the biochemical engineering concentration, students should take the following six courses and two electives selected from the subsequent lists:

BIOL 300	Dynamics of Biological Systems: A Quantitative Introduction to Biology	3
BIOL 301	Biotechnology Laboratory: Genes and Genetic Engineering	3
BIOC 307	Introduction to Biochemistry: From Molecules To Medical Science	4
BIOC 308	Molecular Biology	4
BIOL 343	Microbiology	3
ECHE 340	Biochemical Engineering	3
Plus any two courses selected from the following:		6
BIOL 334	Structural Biology	
BIOL 382	Drugs, Brain, and Behavior	
PHRM 309	Principles of Pharmacology	
Total Units		26

Pre-Medical Concentration

The Pre-Medical Concentration provides a focused approach to medical school preparation for chemical engineering majors. By using the flexibility provided by science and technical electives in the curriculum, students are able to pursue courses that provide the background needed for medical school. Students take the following courses to meet the course requirements of most medical schools.

CHEM 113	Principles of Chemistry Laboratory (Freshman, Fall)	2
BIOL 214	Genes, Evolution and Ecology (Freshman, Spring)	3

CHEM 223	Introductory Organic Chemistry I (Sophomore, Fall)	3
or CHEM 323	Organic Chemistry I	
CHEM 224	Introductory Organic Chemistry II (Sophomore, Spring)	3
or CHEM 324	Organic Chemistry II	
CHEM 233	Introductory Organic Chemistry Laboratory I (Junior, Fall)	2
BIOC 307	Introduction to Biochemistry: From Molecules To Medical Science (Junior, Fall)	4
BIOL 215	Cells and Proteins (Junior, Fall)	3
CHEM 234	Introductory Organic Chemistry Laboratory II (Junior, Spring)	2
Total Units		22

A student enrolled in this concentration satisfies the material and science electives requirements as well as the breadth elective sequence requirements of the program. Further, the student does not have to take CHEM 290 Chemical Laboratory Methods for Engineers.

Approved Breadth Elective Sequences

Biochemical Engineering (Advisor: Dr. Qutubuddin)

BIOC 307	Introduction to Biochemistry: From Molecules To Medical Science (Fall)	4
BIOL 343	Microbiology (Spring)	3
ECHE 340	Biochemical Engineering (Spring)	3
Total Units		10

Biomedical Engineering (Advisor: Dr. Baskaran)

EBME 201	Physiology-Biophysics I (Fall)	3
EBME 202	Physiology-Biophysics II (Spring)	3
One additional course selected from:		3
EBME 309	Modeling of Biomedical Systems (Spring)	
ECHE 355	Quantitative Molecular, Cellular and Tissue Bioengineering (Spring)	
Total Units		9

Computing (Advisor: Dr. Lacks)

EECS 281	Logic Design and Computer Organization	4
EECS 346	Engineering Optimization (Spring)	3
One additional EECS course at 200 level or above		3-4
Total Units		10-11

Electrochemical Engineering (Advisor: Dr. Landau)^h

ECHE 381	Electrochemical Engineering (Spring)	3
ECHE 383	Chemical Engineering Applied to Microfabrication and Devices (Fall)	3
One additional course selected from:		3
EMSE 343	Materials for Electronics and Photonics	
EECS 309	Electromagnetic Fields I (Fall)	

EECS 321	Semiconductor Electronic Devices (Spring)	
Total Units		9

Electronic Materials (Advisor: Dr. Liu)^h

ECHE 383	Chemical Engineering Applied to Microfabrication and Devices (Fall)	3
EECS 309	Electromagnetic Fields I (Fall)	3
One additional course selected from:		3
EMSE 343	Materials for Electronics and Photonics	
EECS 321	Semiconductor Electronic Devices (Spring)	
Total Units		9

Energy (Advisor: Dr. Savinell)

ECHE 381	Electrochemical Engineering (Fall)	3
Plus two courses selected from the following:		6-7
EECS 312	Introduction to Electric Power Systems	
EECS 374	Advanced Control and Energy Systems	
Approved energy course in Engineering, Physics, Chemistry, Management, or Law		
Total Units		9-10

Environmental Engineering (Advisor: Dr. Feke)

ECIV 368	Environmental Engineering (Spring)	3
Two additional courses selected from the following:		6
ECIV 351	Engineering Hydraulics and Hydrology	
ECIV 361	Water Resources Engineering (Fall)	
ECIV 362	Solid and Hazardous Waste Management (Spring)	
ESTD 398	Seminar in Environmental Studies (Fall)	
EEPS 303	Environmental Law	
EEPS 321	Hydrogeology	
EECS 342	Introduction to Global Issues (Fall)	
Total Units		9

Management/Entrepreneurship (Advisor: Dr. Savinell)

BAFI 355	Corporate Finance (Fall)	3
ACCT 203	Survey of Accounting	3
One additional course selected from the following:		3
ENTP 311	Entrepreneurship and Wealth Creation (Spring)	
ENTP 310	Entrepreneurial Finance - Undergraduate (Fall)	
Total Units		9

Polymer Science (Advisor: Dr. Mann)^h

EMAC 270	Introduction to Polymer Science and Engineering (Fall)	3
Plus any two courses selected from:		6
EMAC 276	Polymer Properties and Design (Fall)	
EMAC 376	Polymer Engineering (Spring)	
EMAC 377	Polymer Processing (Spring)	
EMAC 378	Polymer Engineer Design Product (Spring)	

EMAC 303	Structure of Biological Materials	
Total Units		9

Research (Advisor: Dr. Martin)

ECHE 396	Research and Innovation (Fall)	3
ECHE 350	Undergraduate Research Project I (Fall)	3
One additional course selected from the following:		3
ECHE 351	Undergraduate Research Project II	
Research elective ⁱ		
Total Units		9

Systems and Control (Advisor: Dr. Lacks)

EECS 346	Engineering Optimization (Spring)	3
EECS 281	Logic Design and Computer Organization (Fall)	4
EECS 304	Control Engineering I with Laboratory (Spring)	3
Total Units		10

BS/MS Advanced Study Sequence (Advisor: Dr. Qutubuddin)

Three courses selected from the following:		9
ECHE 460	Thermodynamics of Chemical Systems (Fall)	
ECHE 461	Transport Phenomena (Spring)	
ECHE 462	Chemical Reaction Engineering (Spring)	
ECHE 475	Chemical Engineering Analysis (Fall)	
Total Units		9

h Courses in these sequences may satisfy the materials elective requirement but do not reduce the total credit hours requirement for the degree.

i Students should take a 300-level undergraduate or introductory graduate course that would be relevant to their research project and is approved by the department.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Chemical Engineering

First Year	Units	
	Fall	Spring
General Physics I - Mechanics (PHYS 121) ^a	4	
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121)	4	
FSxx SAGES First Seminar ^b	4	
Introduction to Chemical Engineering at Case (ECHE 151)	1	
PHED (2 half semester courses)		
General Physics II - Electricity and Magnetism (PHYS 122) ^a	4	
Chemistry of Materials (ENGR 145)	4	
Calculus for Science and Engineering II (MATH 122) ^a or Calculus II (MATH 124)	4	
Elementary Computer Programming (ENGR 131)	3	
USxx SAGES University Seminar I ^b	3	

PHED (2 half semester courses)		
Year Total:	17	18

Second Year	Units	
	Fall	Spring
Introductory Organic Chemistry I (CHEM 223) ^a or Organic Chemistry I (CHEM 323)	3	
Calculus for Science and Engineering III (MATH 223) ^a or Calculus III (MATH 227)	3	
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)	4	
Introduction to Chemical Systems (ECHE 260)	3	
USxx 2xx SAGES University Seminar II ^b	3	
Elementary Differential Equations (MATH 224) ^a or Differential Equations (MATH 228)		3
Statistics for Experimenters (STAT 313)		3
Thermodynamics of Chemical Systems (ECHE 363)		3
Science elective ^e		3
Humanities/Social Science elective I		3
Year Total:	16	15

Third Year	Units	
	Fall	Spring
Transport Phenomena for Chemical Systems (ECHE 360)	4	
Process Control (ECHE 367)	4	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
Chemical Laboratory Methods for Engineers (CHEM 290)	3	
Breadth elective sequence I ^c	3	
Separation Processes (ECHE 361)		3
Measurements Laboratory (ECHE 365)		3
Professional Communication for Engineers (ENGR 398) ^d		1
Professional Communication for Engineers (ENGL 398) ^d		2
Chemical Reaction Processes (ECHE 364)		3
Humanities/Social Science elective II		3
Year Total:	18	15

Fourth Year	Units	
	Fall	Spring
Process Analysis and Design (ECHE 398)	3	
Chemical Engineering Laboratory (ECHE 362)	4	
Materials elective ^f	3	
Breadth Elective Sequence II ^c	3	
Humanities/Social Science elective III	3	
Chemical Engineering Design Project (ECHE 399) ^g		3
Statics and Strength of Materials (ENGR 200)		3
Physical Chemistry II (CHEM 336)		3
Breadth elective sequence III ^c		3
Humanities/Social Science elective IV		3

Year Total:	16	15
Total Units in Sequence:		130

Hours required for graduation: 129-131 (depending on breadth elective sequence)

- * Higher number (advanced or honors) courses are available to students by invitation only.
- b Must take one course from each thematic group: FSSY or USSY — Thinking about the symbolic world, FSNA or USNA—Thinking about the natural world and FSSO or USSO—Thinking about the social world. Specific seminar topics will change periodically.
- c A three-course (9 credit hours minimum) breadth sequence (approved by the Chemical and Biomolecular Engineering faculty). Pre-approved sequences include: biochemical engineering, biomedical engineering, computing, electrochemical engineering, electronic materials processing, energy, environmental engineering, management, polymer science, systems and control, and advanced study (BS/MS).
- d SAGES Departmental Seminar.
- e Science elective, chosen from:
 - PHYS 221 Introduction to Modern Physics
 - CHEM 224 Introductory Organic Chemistry II
 - CHEM 311 Inorganic Chemistry I
 - BIOL 300 Dynamics of Biological Systems: A Quantitative Introduction to Biology
- f One Materials elective is required. Suggested courses include:
 - EMAC 270 Introduction to Polymer Science and Engineering
 - EMAC 276 Polymer Properties and Design
 - EMSE 343 Materials for Electronics and Photonics
- g SAGES Capstone Course

Five-Year Combined BS/MS Program

This program offers outstanding undergraduate students the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree. (Normally, it takes two years beyond the BS to earn an MS degree.) In this program, an undergraduate student can take up to nine hours of graduate credit that simultaneously satisfies undergraduate degree requirements. Typically, students in this program start their research leading to the MS thesis in the fall semester of the senior year. The BS degree is awarded at the completion of the senior year. Application for admission to the five-year BS/MS program is made after completion of five semesters of coursework. Minimum requirements are a 3.2 grade point average and the recommendation of the department.

Five-and-a Half Year Cooperative BS/MS Program

The cooperative bachelor's/master's program enables outstanding students who are enrolled in the cooperative education program to earn an MS in one semester beyond the BS 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 BS degree. Upon completion of an additional 12 credits of graduate work the following semester, the student receives the MS degree (non-thesis). Application for admission to the five-and a-half-year co-op BS/MS 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, satisfactory performance in the previous co-op assignment, and the recommendation of the department.

Minor in Chemical Engineering

The minor in chemical engineering is for students majoring in other disciplines. A minimum of 17 hours in chemical engineering courses are required for the minor. The required courses are:

ENGR 225	Thermodynamics, Fluid Dynamics, Heat and Mass Transfer	4
ECHE 260	Introduction to Chemical Systems	3
ECHE 360	Transport Phenomena for Chemical Systems	4
Plus two courses selected from the following:		6-7
ECHE 361	Separation Processes	
ECHE 363	Thermodynamics of Chemical Systems	
ECHE 364	Chemical Reaction Processes	
ECHE 365	Measurements Laboratory	
ECHE 367	Process Control	

Total Units 17-18

Graduate Programs

Master of Science Program

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

Plan A

ECHE 401	Chemical Engineering Communications	1
Six graduate-level courses		18
MS thesis research		9
Total Units		28

Plan B

Part-time students, and those in the 5-1/2-year BS/MS 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 MS 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 MS students are required to include the following courses in their program:

ECHE 460	Thermodynamics of Chemical Systems	3
ECHE 461	Transport Phenomena	3
ECHE 462	Chemical Reaction Engineering	3
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. Full-time MS students are expected to do some teaching or mentoring 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 and Biomolecular Engineering also participates in the practice-oriented Master of Engineering program offered by the Case School of Engineering. The Department of Chemical and Biomolecular 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 a comprehensive understanding of related subjects together with a demonstration of the ability to perform independent research, to suggest new areas for research, and to communicate results in an acceptable manner. For students entering the PhD program with a BS degree, a total of 12 courses (36 credit hours) is required. Course requirements for students entering with MS degrees are adjusted to account for work done at other universities, but a minimum of 6 courses (18 credit hours) must be taken at CWRU. The course requirements for students entering with a BS degree are as follows:

Core Courses

All programs of study must include:

ECHE 460	Thermodynamics of Chemical Systems	3
ECHE 461	Transport Phenomena	3
ECHE 462	Chemical Reaction Engineering	3
ECHE 475	Chemical Engineering Analysis	3
Total Units		12

A minimum of six additional graduate courses (in chemical engineering or other departments) must be taken. At least one of these electives must be in a Basic Science (i.e., Chemistry, Physics, Biology, Biochemistry, Mathematics, or Statistics). All PhD programs of study must include two mathematics or statistics courses, one of which must be ECHE 475 (listed above as a "core" course). With department approval, a 300-level lecture course can be used to replace an elective course.

Professional Development Courses

The balance of the PhD course work (two courses in addition to the TA assignment) is met through the professional development courses. All PhD students are required to assist in three teaching experiences as part of their degree requirements. Students enroll in the following courses for these teaching experiences.

ECHE 401	Chemical Engineering Communications	1
ECHE 402	Chemical Engineering Communications II	2
ECHE 470	Graduate Research Colloquium *	3
ECHE 400T	Graduate Teaching I	0
ECHE 500T	Graduate Teaching II	0
ECHE 600T	Graduate Teaching III	0
Total Units		6

* Six semesters of ECHE 470 Graduate Research Colloquium are required.

Comments on PhD 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 course at another school. In these cases, the student must submit a statement with the Planned Program of Study justifying the departure from the guidelines. It should be noted that the above guidelines are a minimum requirement. All programs are chosen with the approval of the student's faculty advisor.

Other Requirements for the PhD Degree

Students who wish to enter the PhD program must pass a First Proposition oral examination (with an accompanying written report) that tests a student's ability to think creatively, grasp new research concepts, and discuss such concepts critically and comprehensively. The First Proposition serves as the qualifying examination for the PhD degree. A Second Proposition focusing on the students own research topic is required by the end of the second year in the program. All PhD students must satisfy the residency requirements of the university and the Case School of Engineering. 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 and Biomolecular Engineering Graduate Student Handbook contains a more detailed description of the department's PhD requirements and a time schedule for their completion.

Facilities

The department is housed in the Albert W. Smith Building and portions of the Bingham 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 one technology enhanced classroom; the undergraduate Unit Operations Laboratory; an undergraduate reading room, named after Prof. Robert V. Edwards; and the normal complement of offices and research laboratories. The lobby of the A.W. Smith Building, renovated by contributions from the James family, often serves as a formal and informal gathering place for students and faculty. The department has exceptionally strong facilities for electrochemical and energy 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 and Biomolecular Engineering, the Department of Chemistry, and the Materials Research Laboratory.

Faculty

Uziel Landau, PhD
(University of California, Berkeley)
Professor and Chair

Electrochemical engineering, modeling of electrochemical systems, electrodeposition, batteries, fuel cells, electrolyzers, corrosion

Rohan N. Akolkar, PhD
(Case Western Reserve University)
Associate Professor

John C. Angus, PhD
(University of Michigan)
Professor Emeritus

Chemical vapor deposition of diamond, electrochemistry of diamond, gallium nitride synthesis

Harihara Baskaran, PhD
(The Pennsylvania State University)
Associate Professor

Transport phenomena in biology and medicine

Donald L. Feke, PhD
(Princeton University)

Professor and Vice Provost for Undergraduate Education

Colloidal and transport phenomena, dispersive mixing, particle science and processing

Daniel Lacks, PhD
(Harvard University)

C. Benson Branch Professor of Chemical Engineering

Molecular simulation, statistical mechanics

Chung-Chiun Liu, PhD
(Case Institute of Technology)

Wallace R. Persons Professor of Sensor Technology and Control

Electrochemical sensors, electrochemical synthesis, electrochemistry related to electronic materials

J. Adin Mann Jr., PhD
(Iowa State University)

Emeritus Professor

Surface phenomena, interfacial dynamics, colloid science, light scattering, biomimetics, molecular electronics, Casimir force (effects)

Heidi B. Martin, PhD
(Case Western Reserve University)

Associate Professor

Conductive diamond films; electrochemical sensors; chemical modification of surfaces for electrochemical and biomedical applications; biomaterials; microfabrication of sensors and devices

Syed Qutubuddin, PhD
(Carnegie Mellon University)

Professor

Surfactant and polymer solutions, separations, nanoparticles, novel polymeric materials, nanocomposites

R. Mohan Sankaran, PhD
(California Institute of Technology)

Associate Professor

Microplasmas, nanoparticle synthesis

Robert F. Savinell, PhD
(University of Pittsburgh)

George S. Dively Professor

Electrochemical engineering, electrochemical reactor design and simulation, electrode processes, batteries and fuel cells

Jesse S. Wainright, PhD
(Case Western Reserve University)

Associate Research Professor

Electrochemical power sources: fuel cells, batteries, supercapacitors; biomedical applications

Courses

ECHE 151. Introduction to Chemical Engineering at Case. 1 Unit.

An introduction to the profession of chemical engineering, its practice in industry, and review of the challenges and opportunities for the profession. The academic programs and curricular enhancements available to students majoring in chemical engineering at CWRU, including breadth sequence sequences and concentrations, undergraduate research, international study opportunities, cooperative education and internships, are presented. In addition to introducing the chemical engineering faculty and their research, a number of guest speakers representing the broad professional opportunities discuss career options with the students. Through lectures and discussions, students are also introduced to topics such as professionalism and ethics. Upperclassmen students conduct their co-op debriefing in the class, sharing experiences and initiating networking. In the lab/recitation section, students in smaller groups conduct experiments on chemical processes, spanning different aspects of the profession, and run computer-based simulations of those experiments. Analysis and discussion of the results will follow. Chemical engineering upperclassmen serve as teaching assistants.

ECHE 250. Honors Research I. 1 - 3 Unit.

A special program which affords a limited number of 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 Unit.

(See ECHE 250.) Recommended preparation: ECHE 250.

ECHE 260. Introduction to Chemical Systems. 3 Units.

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. Prereq: CHEM 111, ENGR 145 and MATH 122.

ECHE 340. Biochemical Engineering. 3 Units.

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. Recommended preparation: BIOC 307, BIOL 343 and ECHE 364, or permission of instructor.

ECHE 350. Undergraduate Research Project I. 3 Units.

This course affords a student the opportunity to conduct research under the guidance of one of the faculty, as part of the Chemical Engineering Research breadth elective sequence. Students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest.

ECHE 351. Undergraduate Research Project II. 3 Units.

This course affords a student the opportunity to conduct research under the guidance of one of the faculty, as part of the Chemical Engineering Research breadth elective sequence. Students who have a strong interest in research are encouraged to discuss research possibilities with the faculty. Assignments are made based on mutual interest. Prereq: ECHE 350.

ECHE 355. Quantitative Molecular, Cellular and Tissue Bioengineering. 3 Units.

Physical and chemical principles associated with kinetics and mass transport. Molecular-cellular components incorporated in quantitative analysis of cellular, tissue, and organ systems. Mathematical and computational modeling developed for diagnostic and therapeutic applications. Offered as EBME 350 and ECHE 355.

ECHE 360. Transport Phenomena for Chemical Systems. 4 Units.

Fundamentals of fluid flow, heat and mass transport from the microscopic and macroscopic perspectives. Applications to chemical systems, including steady and transient operations, convective and molecular (conduction and diffusion) effects, and interfacial transport. Design of unit operations (e.g., heat exchangers). Heat and mass transfer analogies. Vector/tensor analysis and dimensional analysis used throughout. Prereq: ENGR 225 and MATH 223.

ECHE 361. Separation Processes. 3 Units.

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 Units.

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 260, ECHE 360, ECHE 361, ECHE 363 and ECHE 364.

ECHE 362D. Chemical Engineering Laboratory in Denmark. 4 Units.

Chemical Engineering Laboratory in Denmark. A version of ECHE 362 taught during the summer at DTU in Lyngby. Prereq: ECHE 260 and ECHE 360 and ECHE 361 and ECHE 363 and ECHE 364.

ECHE 363. Thermodynamics of Chemical Systems. 3 Units.

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 Prereq or Coreq: ENGR 225.

ECHE 364. Chemical Reaction Processes. 3 Units.

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. Recommended preparation: ECHE 360. Prereq: ECHE 260 and MATH 224.

ECHE 365. Measurements Laboratory. 3 Units.

Laboratory introduction to the measurement process 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. Example projects cover steady and unsteady state heat transfer, momentum transfer, and the first law of thermodynamics. Recommended preparation: ECHE 360. Prereq: ECHE 260, ECHE 363 and ENGR 225.

ECHE 367. Process Control. 4 Units.

Theoretical and practical aspects of feedback control of chemical processes. The course involves extensive use of computer software with some exams taken using the computer. Short laboratories and Labview training are integrated into the course. 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. The Labview training covers programming basics, interfacing to a data acquisition system, and incorporating control algorithms.. Prereq: ECHE 260 and MATH 224.

ECHE 370. Fluid Mechanics for Chemical Systems. 3 Units.

This course introduces the physical and mathematical concepts associated with the motion of material and the transfer of momentum. These concepts will be applied to the analysis of engineering systems to obtain both exact solutions and practical estimates. Both analytical and numerical solutions will be utilized.

ECHE 371. Heat and Mass Transfer for Chemical Systems. 3 Units.

This course introduces the physical and mathematical concepts associated with the transfer of heat and mass. These will be applied to the analysis of engineering situations to obtain both exact solutions and practical estimates. Analytical and numerical solutions will be utilized.

ECHE 381. Electrochemical Engineering. 3 Units.

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. Recommended preparation: ECHE 260 or permission of instructor. Offered as ECHE 381 and ECHE 480.

ECHE 383. Chemical Engineering Applied to Microfabrication and Devices. 3 Units.

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 project on some technical aspect of microfabrication technology or devices. Recommended preparation: ECHE 363 and ECHE 371. Offered as ECHE 383 and ECHE 483.

ECHE 396. Research and Innovation. 3 Units.

This course is an opportunity for undergraduate students to experience research--how to approach a research problem, design experiments and analyze data. This will be accomplished through (a) hands-on laboratory experiences with important research techniques, (b) assignment of open-ended projects on research topics, and (c) discussion of specific interdisciplinary research being pursued at Case. It is meant to be a mechanism for students to become involved in a research project; the final assignment is to submit a proposal for this project. Example interdisciplinary research areas to be included are Fuel Cells and Batteries, Sensors, Biomaterials, and Micro and Nano-fabricated Devices.

ECHE 397. Special Topics in Chemical Engineering. 3 Units.

Special topics within an area of chemical engineering.

ECHE 398. Process Analysis and Design. 3 Units.

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 260, ECHE 360, ECHE 361, ECHE 363 and ECHE 364.

ECHE 399. Chemical Engineering Design Project. 3 Units.

This is a course that uses the small teams approach to solve chemical process design problems. Numerous exercises involving process design are used to integrate material taught in previous and concurrent courses. This includes application of computer based design tools, economics, scheduling, decision making with uncertainty, and proposal and report preparation. This work leads to one comprehensive process design project done by the class, which includes a written and oral report. Counts as SAGES Senior Capstone. Prereq: ECHE 365, ECHE 367, ECHE 398.

ECHE 400T. Graduate Teaching I. 0 Units.

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. Recommended preparation: Entering Ph.D. student in Chemical Engineering.

ECHE 401. Chemical Engineering Communications. 1 Unit.

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 402. Chemical Engineering Communications II. 2 Units.

This course is a continuation of ECHE 401 and is designed to develop skills in writing proposals for funding research projects. The federal requirements are reviewed for submitting proposals to the major granting agents including NSF, NIH and DoD. We will study strategies for developing fundable projects. Each student will submit a research proposal for a thesis project and do an oral presentation of the project.

ECHE 460. Thermodynamics of Chemical Systems. 3 Units.

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. Recommended preparation: ECHE 363.

ECHE 461. Transport Phenomena. 3 Units.

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. Recommended preparation: ECHE 360.

ECHE 462. Chemical Reaction Engineering. 3 Units.

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. Recommended preparation: ECHE 364.

ECHE 464. Surfaces and Adsorption. 3 Units.

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 reactions. Recommended preparation: CHEM 335 or equivalent.

ECHE 466. Colloid Science. 3 Units.

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. Recommended preparation: CHEM 335.

ECHE 469. Chemical Engineering Seminar. 0 Units.

Distinguished outside speakers present current research in various topics of chemical engineering science. Graduate students also present technical papers based on thesis research.

ECHE 470. Graduate Research Colloquium. 0.5 Units.

Outside speakers present lectures on their current research. Various topics in the areas of chemical engineering science, basic and applied chemistry, bioengineering, material science, and applied mathematics are covered in the lectures. Graduate students also present technical papers based on their own research. Students are graded on the submission of one-page summary reports on any two lectures.

ECHE 474. Biotransport Processes. 3 Units.

Biomedical mass transport and chemical reaction processes. Basic mechanisms and mathematical models based on thermodynamics, mass and momentum conservation. Analytical and numerical methods to simulate in vivo processes as well as to develop diagnostic and therapeutic methods. Applications include transport across membranes, transport in blood, tumor processes, bioreactors, cell differentiation, chemotaxis, drug delivery systems, tissue engineering processes. Recommended preparation: EBME 350 and EBME 409 or equivalent. Offered as EBME474 and ECHE 474.

ECHE 475. Chemical Engineering Analysis. 3 Units.

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). Recommended preparation: MATH 224.

ECHE 477. Data Acquisition and LabVIEW Bootcamp. 1 Unit.

This course will introduce and implement basic data acquisition concepts and LabVIEW virtual instrumentation programming, providing hands-on experience with hardware and software. It is intended to help those with little or no data acquisition experience to get started on setting up data acquisition for their application. No prior experience with LabVIEW is required. Consult with the instructor for additional details.

ECHE 480. Electrochemical Engineering. 3 Units.

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. Recommended preparation: ECHE 260 or permission of instructor. Offered as ECHE 381 and ECHE 480.

ECHE 481. Corrosion Fundamentals. 3 Units.

This course will cover fundamentals of corrosion, including thermodynamic and kinetic aspects of the electrochemical reactions leading to corrosion. Salient features of the various types of corrosion will be reviewed, with an emphasis on fundamental mechanisms. Electrochemical testing, corrosion monitoring and techniques to stifle corrosion will be discussed. After completion of this course, students will be able to classify corrosion systems, understand the mechanisms underlying corrosion, and outline strategies to design corrosion-resistant systems.

ECHE 483. Chemical Engineering Applied to Microfabrication and Devices. 3 Units.

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 project on some technical aspect of microfabrication technology or devices. Recommended preparation: ECHE 363 and ECHE 371. Offered as ECHE 383 and ECHE 483.

ECHE 500T. Graduate Teaching II. 0 Units.

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. Recommended preparation: Ph.D. student in Chemical Engineering.

ECHE 580. Special Topics. 3 Units.

Special topics in chemical engineering. Prereq: Consent of instructor.

ECHE 590. Topics in Materials Engineering. 3 Units.

Seminar course focusing on topics related to materials engineering. Typical subjects include processing and properties of electronic and nanomaterials, composites and dispersions; mixing of particles and agglomerates; electrodeposition of alloys; molecular level simulations. Students will be assigned readings from book chapters, classical articles and state of the art publications. A discussion leader (pre-assigned) will be responsible for introducing the papers and leading a critical discussion. Active student participation in the discussions is expected.

ECHE 600T. Graduate Teaching III. 0 Units.

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. Recommended preparation: Ph.D. student in Chemical Engineering.

ECHE 601. Independent Study. 1 - 18 Unit.**ECHE 651. Thesis M.S.. 1 - 18 Unit.****ECHE 660. Special Problems. 1 - 18 Unit.**

Research course taken by Plan B M.S. students.

ECHE 701. Dissertation Ph.D.. 1 - 18 Unit.

Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Civil Engineering

The Department of Civil Engineering offers programs of study in environmental, geotechnical, and structural engineering, construction engineering and management, and engineering mechanics.

Civil engineers plan, design, and construct facilities for meeting the needs of modern society. Civil engineers also help to reduce the environmental impact of these designs to help make modern society more sustainable. 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, contaminated sediments, infrastructure materials and infrastructure systems optimization.

Mission Statement and Objectives

The Department of Civil Engineering developed its own mission statement and educational objectives that are consistent with those of the Engineering School. This process involved the entire Civil Engineering faculty and the Civil Engineering Advisory Committee. It was conducted during regular faculty meetings and special meetings called for this purpose. It is an ongoing process.

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.

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:

- Random vibration
- Engineering materials
- Behavior of reinforced and prestressed concrete
- Wind engineering
- Earthquake analysis and design of structures
- Finite element methods
- Nondestructive Testing of Structures
- Passive and active control of the vibration of structures
- Transient response of nonlinear structures
- Blast loading of structures
- Modeling of micro electromechanical systems
- Fracture mechanics
- Multiscale simulation
- Modeling of concrete, of geomaterials and of asphalt concrete
- High and low-cycle fatigue
- Geotechnical/Pavement Materials
- Static behavior of anisotropic clays and sands
- Soil liquefaction
- Bifurcation and shear banding in soils
- Centrifuge modeling of static and dynamic soil behavior
- Dynamic soil structure interaction
- Non-destructive testing evaluation of soils and pavement materials
- Measurement of dynamic soil properties
- Design of Structures for High-Speed Vehicles
- Stability of tailings dams
- Environmental Engineering
- Environmentally conscious manufacturing
- Remediation of "old" metal-contaminated soils
- Brownfields/structural remediation
- Environmental modeling/software development
- Environmental decision analysis
- Geoenvironmental engineering
- Environmental fluid mechanics
- Sediment remediation
- In-situ remediation of non-aqueous phase liquids
- Environmental chemistry
- Bioremediation
- Sustainable engineering
- Structural health monitoring
- Transportation safety
- Infrastructure engineering
- Non-destructive Testing
- Sensor technology
- Smart materials
- Energy structures and geotechnology
- Biofuel development
- Urban hydraulics

- Soil contamination standards
- Intelligent infrastructure and transportation system
- Driver safety
- Building materials
- Sustainability

Undergraduate Programs

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 or environmental engineering; 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 allows the student to spend time working full-time in an engineering capacity with a contractor, consulting engineer, architect, or materials supplier during the course of his or her education. This learning experience is designed to intergrate classroom theory with practical experience and professional development.

The Bachelor of Science degree program in Civil Engineering is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

The curriculum has been designed so that the student chooses a sequence at least 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. Department approval and a minimum of 15 credit hours are required.

Most classes in the Civil Engineering Department have enrollment of less than 25 so the students have opportunities to develop close relationships with the faculty. Students also have opportunities to gain practical experience as well as earn a supplemental income by assisting faculty members on consulting work during vacation periods.

Program Educational Objectives

1. Graduates of the ECIV Program will enter the profession of Civil Engineering and advance to positions of greater responsibility and leadership, in line with ASCE Professional Grade Descriptions.
2. Graduates of the ECIV Program will enter and successfully progress in, or complete, advanced degree programs within their fields of choice.

3. Graduates of the ECIV Program will progress toward or complete professional registration and licensure.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Civil Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics (including differential equations) and science (including calculus-based physics and general chemistry) and one additional area of science.
- an ability to design and conduct experiments, as well as to analyze and interpret data in more than one area of civil engineering.
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.
- an ability to function on multi-disciplinary teams.
- an ability to identify, formulate, and solve engineering problems.
- an understanding of professional and ethical responsibility and the role of civil engineers in providing for the safety and well-being of the general public.
- an ability to communicate effectively in written and oral form.
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.
- a recognition of the need for, and an ability to engage in life-long learning.
- a knowledge of contemporary issues.
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice and the design of functional civil engineering facilities.
- proficiency in probability and statistics, as applied to civil engineering design and planning issues.
- an understanding of professional practice issues, including the role of civil engineering design and management professionals in the construction process, public policy and leadership.
- an ability to develop an understanding of the importance of professional licensure and the ethical use of a professional license.

Bachelor of Science in Engineering

Required Courses: Major in Civil Engineering

ECIV 160	Surveying and Computer Graphics	3
ECIV 211	Civil Engineering Materials	3
ECIV 310	Strength of Materials	3
ECIV 320	Structural Analysis I	3
ECIV 322	Structural Design I	3
ECIV 330	Soil Mechanics	4
ECIV 340	Construction Management	3
ECIV 351	Engineering Hydraulics and Hydrology	3
ECIV 360	Civil Engineering Systems	3
ECIV 368	Environmental Engineering	3
ECIV 398	Civil Engineering Senior Project	3
Related Required Courses		
EMAE 181	Dynamics	3
EMAE 250	Computers in Mechanical Engineering	3

A minimum of four courses of the following technical elective sequences, two of which must be from civil engineering: 15

Structural Engineering

ECIV 321	Structural Analysis II
ECIV 323	Structural Design II
ECIV 411	Elasticity, Theory and Applications
ECIV 420	Finite Element Analysis
ECIV 421	Advanced Reinforced Concrete Design
ECIV 422	Advanced Structural Steel Design
ECIV 423	Prestressed Concrete Design
ECIV 424	Structural Dynamics
ECIV 425	Structural Design for Dynamic Loads
ECIV 426	Structural Reliability
ECIV 430	Foundation Engineering
ECIV 452	Infrastructure Aging and Assessment Technologies
ECIV 585	Fracture Mechanics

Geotechnical Engineering

ECIV 323	Structural Design II
ECIV 411	Elasticity, Theory and Applications
ECIV 420	Finite Element Analysis
ECIV 430	Foundation Engineering
ECIV 431	Special Topics in Geotechnical Engineering
ECIV 432	Mechanical Behavior of Soils
ECIV 437	Pavement Analysis and Design
ECIV 433	Soil Dynamics
EEPS 330	Geophysical Field Methods and Laboratory

Engineering Mechanics

ECIV 411	Elasticity, Theory and Applications
ECIV 420	Finite Element Analysis
ECIV 433	Soil Dynamics
ECIV 424	Structural Dynamics
ECIV 432	Mechanical Behavior of Soils

Environmental Engineering

ECIV 361	Water Resources Engineering
ECIV 362	Solid and Hazardous Waste Management
ECIV 450	Environmental Engineering Chemistry
ECIV 460	Environmental Remediation
ECIV 461	Environmental Engineering Biotechnology
EEPS 220	Environmental Geology

Pre-Architecture

ARTS 106	Creative Drawing I
ARTS 206	Creative Drawing II
ARTS 302	Architecture and City Design I
ARTS 304	Architecture and City Design III
ECIV 323	Structural Design II

Construction Engineering and Management

BAFI 355	Corporate Finance
ECIV 341	Construction Scheduling and Estimating
ECIV 430	Foundation Engineering
ECON 369	Economics of Technological Innovation and Entrepreneurship
ECON 368	Environmental Economics

ECIV 437	Pavement Analysis and Design	
Total Units		52

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.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Civil Engineering

First Year	Units	
	Fall	Spring
Open elective		3
Principles of Chemistry for Engineers (CHEM 111)		4
Elementary Computer Programming (ENGR 131)		3
FSXX SAGES First Seminar		4
Calculus for Science and Engineering I (MATH 121)		4
PHED (two half semester classes)		
SAGES University Seminar I		3
Chemistry of Materials (ENGR 145)		4
Calculus for Science and Engineering II (MATH 122)		4
General Physics I - Mechanics (PHYS 121)		4
PHED (two half semester classes)		
Year Total:	18	15
Second Year	Units	
	Fall	Spring
SAGES University Seminar II		3
Surveying and Computer Graphics (ECIV 160)		3
Computers in Mechanical Engineering (EMAE 250)		3
Statics and Strength of Materials (ENGR 200)		3
Calculus for Science and Engineering III (MATH 223)		3
General Physics II - Electricity and Magnetism (PHYS 122)		4
Humanities or Social Science		3
Strength of Materials (ECIV 310)		3
Dynamics (EMAE 181)		3
Introduction to Circuits and Instrumentation (ENGR 210)		4
Elementary Differential Equations (MATH 224)		3
Year Total:	19	16
Third Year	Units	
	Fall	Spring
Humanities or Social Science		3
Civil Engineering Materials (ECIV 211)		3
Structural Analysis I (ECIV 320)		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)		4

Professional Communication for Engineers (ENGR 398)		3
& Professional Communication for Engineers (ENGL 398) ^a		
Structural Design I (ECIV 322)		3
Soil Mechanics (ECIV 330)		4
Engineering Hydraulics and Hydrology (ECIV 351)		3
Environmental Engineering (ECIV 368)		3
Approved elective ^b		3
Year Total:	16	16

Fourth Year	Units	
	Fall	Spring
Humanities or Social Science		3
Construction Management (ECIV 340)		3
Civil Engineering Senior Project (ECIV 398)		3
Approved elective ^b		3
Approved elective ^b		3
Humanities or Social Science		3
Civil Engineering Systems (ECIV 360)		3
Approved Natural Science Elective		3
Approved elective ^b		3
Open elective		3
Year Total:	15	15
Total Units in Sequence:		130

a ENGR 398 and ENGL 398 must be taken concurrently.

b Must be part of an approved sequence

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:

ENGR 200	Statics and Strength of Materials	3
12 credit hours from one of the following areas: *		12
Solid Mechanics		
ECIV 310	Strength of Materials	
ECIV 411	Elasticity, Theory and Applications	
ECIV 420	Finite Element Analysis	
Structural & Geotechnical Engineering		
ECIV 211	Civil Engineering Materials	
ECIV 320	Structural Analysis I	
ECIV 321	Structural Analysis II	
ECIV 322	Structural Design I	
ECIV 323	Structural Design II	
ECIV 330	Soil Mechanics	
ECIV 430	Foundation Engineering	
ECIV 433	Soil Dynamics	
ECIV 437	Pavement Analysis and Design	3
Construction Engineering and Management *		
ECIV 340	Construction Management	
ECIV 341	Construction Scheduling and Estimating	

ACCT 203	Survey of Accounting	
BAFI 355	Corporate Finance	
COGS 303	SAGES Departmental Seminar: Current Controversies in Cognitive Science (acct 203)	
Total Units		18

* Approval of the department is required.

Minor in Environmental Engineering

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

ENGR 225	Thermodynamics, Fluid Dynamics, Heat and Mass Transfer	4
EEPS 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 460	Environmental Remediation	3

Graduate Programs

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 from Case Western Reserve University. Recent advanced degree recipients have found positions in universities, consulting firms, state and federal agencies, aerospace firms, and the energy industry.

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 study plans may include a research oriented thesis, a practice oriented project or only courses plus a comprehensive exam. For students working toward the Doctor of Philosophy degree a research dissertation is required.

The department also encourages undergraduate students to make use of the university's BS/MS program to pursue advanced studies in Civil Engineering. Undergraduates should apply for the BS/MS program in their junior year so they are able to select senior electives that will also satisfy MS degree requirements. Up to 9 hours of senior electives may be counted in both the BS and MS program thus allowing the student to complete the MS degree in the fifth year of study. Fifth year tuition scholarships may also be available. For more information students should discuss the BS/MS program with their Academic Advisor and/or the department BS/MS program coordinator.

Facilities

Vanderhoof-Schuetz Structural Laboratory

The Vanderhoof-Schuetz Structural Laboratory and Educational facility features a 2400 ft² cellular strong floor and a 28 ft. high, L-shaped cellular strong wall. The strong wall includes a vertical cell for testing tall specimens with loads up to 1000kips. A 15-ton crane, a scissors lift, and a forklift truck are available for positioning specimens. A 95 gpm hydraulic pump powers servo-hydraulic actuators for applying static or dynamic forces. The laboratory has a variety of instrumentation and data

acquisition equipment. A 6 ft x 6 ft uni-axial shaking table is available for seismic testing of small physical models.

Environmental Engineering Laboratory

This laboratory is one in a suite of 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 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 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 Laboratory

This laboratory is designed to support physical research on the applied science and design of remediation engineering. 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 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. A 20 g-tons fully automated centrifuge with a servo-hydraulic earthquake shaker is in operation. The laboratory has a full set of equipment for TDR tests.

Haptic Research Laboratory

The haptic interface laboratory hosts two state-of-the-art driving simulators. It provides holistic driving simulations for advanced research, education and training in the area of transportation safety, human perception and human-machine interface.

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. 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.

Civil Engineering Study Lounge

This study area is designed to supplement the computer laboratories with a more quiet workplace for individual or group study.

ASCE Lounge

Provides a student controlled venue for hosting American Society of Civil Engineers (ASCE) student chapter activities.

Miller Library

The Miller Library named in honor of Graig J. Miller, a former Civil Engineering Faculty member, acts as both a library and as the Department's premier meeting space.

Vose Room

The department also shares use of the Vose Room equipment for meetings and video conferencing.

Faculty

Xiangwu (David) Zeng, PhD, PE
(Cambridge University)

Chair and Frank H. Neff Professor

Geotechnical earthquake engineering; centrifuge modeling; foundation vibration

Dario A. Gasparini, PhD
(Massachusetts Institute of Technology)

Professor

Structures; wind and earthquake engineering; applied random processes; history of engineering

Aaron A. Jennings, PhD, PE
(University of Massachusetts)

Professor

Environmental and geoenvironmental engineering; groundwater contamination; hazardous waste management; uncertainty analysis for environmental models

Brian Metrovich, PhD
(Lehigh University)

Associate Professor

Structural engineering, fatigue and fracture mechanics, steel structures, atomistic modeling of failure phenomena, structural health monitoring, and nondestructive evaluation

Michael Pollino, PhD, PE
(University at Buffalo)

Assistant Professor

Structural engineering; seismic analysis and design, rehabilitation of structures and civil infrastructure, large scale experimental testing of structural systems and sub-assemblages, structural dynamics, steel structures

Kurt. R. Rhoads, PhD, PE
(Stanford University)

Assistant Professor

Environmental Engineering; Fate of organic pollutants, bioremediation, algal biofuel development

Adel S. Saada, PhD, PE
(Princeton University)

Professor

Mechanics of materials; static and dynamic mechanical behavior of soils; foundation engineering

Xiong (Bill) Yu, PhD, PE
(Purdue University)

Associate Professor

Geotechnical engineering; infrastructure; construction material testing; information technology

Emeritus Faculty

J. Ludwig Figueroa, PhD
(University of Illinois)

Professor Emeritus

Arthur A. Huckelbridge, DEng, PE
(University of California Berkeley)

Professor Emeritus

Adjunct Faculty

Terrance Cybulski, Adjunct Lecturer

Philip DeSantis, Adjunct Professor

Dan Ghiocel, Adjunct Professor

Kenneth L. Klika, Adjunct Professor

Mark D. Rokoff, Adjunct Assistant Professor

John Stevenson, Adjunct Professor

Lance Wanamaker, Adjunct Lecturer

Katie Wheaton, Adjunct Lecturer

Erwin V. Zaretsky, Adjunct Professor

Staff

Nancy A. Longo, Department Assistant

Courses

ECIV 160. Surveying and Computer Graphics. 3 Units.

Principles and practice of surveying; error analysis, topographic mapping, introduction to photogrammetry and GIS; principles of graphics; computer-aided-drafting. Laboratory.

ECIV 211. Civil Engineering Materials. 3 Units.

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. Recommended preparation: Concurrent enrollment in ECIV 310.

ECIV 300. Undergraduate Research. 3 Units.

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.

ECIV 310. Strength of Materials. 3 Units.

Mechanical properties of materials, deformations, stresses, strains and their transformation. Torsion of structural and machine elements, pressure vessels and beams under combined loading. Deflection and statically indeterminate beams. Energy methods and column stability. Prereq: ENGR 200.

ECIV 320. Structural Analysis I. 3 Units.

Static, linear, structural analysis of trusses and frames for member forces and displacements. Analysis of cables and arches. Behavior of statically determinate and indeterminate systems using stiffness and flexibility formulations. Introduction to structural analysis software. Structural load calculations and load path. Recommended preparation: ECIV 310. Prereq: ENGR 200.

ECIV 321. Structural Analysis II. 3 Units.

Stiffness and flexibility formulations for frames and grids, and matrix methods. Mechanism limit state analysis of frames. 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 Units.

Professional role of a structural engineer. Professional and legal responsibilities. Design of structures, beams, columns, beam-columns, and connections. Structures of steel and reinforced concrete. Recommended preparation: ECIV 320.

ECIV 323. Structural Design II. 3 Units.

Continuation of ECIV 322. Collapse limit state analysis/design, 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, intro to prestressed concrete design and timber design. Recommended preparation: ECIV 320 and ECIV 322.

ECIV 330. Soil Mechanics. 4 Units.

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, and design of embankments, retaining walls and footings. Standard laboratory tests performed for the determination of the physical and mechanical properties of soils. Laboratory. Recommended preparation: ECIV 310.

ECIV 340. Construction Management. 3 Units.

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 Units.

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. Recommended preparation: ECIV 340 and consent of instructor.

ECIV 351. Engineering Hydraulics and Hydrology. 3 Units.

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. Recommended preparation: Concurrent enrollment in ENGR 225.

ECIV 360. Civil Engineering Systems. 3 Units.

Introduction to probability, random variables, and non-deterministic modeling. Decision-making in civil engineering. Engineering economics. Introduction to optimization and linear programming. Reliability analysis.

ECIV 361. Water Resources Engineering. 3 Units.

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. Recommended preparation: ECIV 351.

ECIV 362. Solid and Hazardous Waste Management. 3 Units.

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 Units.

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 396. Civil Engineering Special Topics I. 1 - 3 Unit.

Special topics in civil engineering in which a regular course is not available. Conferences and report.

ECIV 397. Civil Engineering Topics II. 3 Units.

Special topics in civil engineering in which a regular course is not available. Conferences and report.

ECIV 398. Civil Engineering Senior Project. 3 Units.

A project emphasizing research and/or design must be completed by all civil engineers. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Counts as SAGES Senior Capstone.

ECIV 400T. Graduate Teaching I. 0 Units.

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. students in Civil Engineering.

ECIV 411. Elasticity, Theory and Applications. 3 Units.

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. Recommended preparation: ECIV 310 or equivalent.

ECIV 420. Finite Element Analysis. 3 Units.

Development and application of finite element methods with emphasis on solid mechanics. Development of truss, beam, shell, and solid elements will be considered. Formulation of isoparametric elements. Meshing and modeling techniques discussed using commercial finite element software. Recommended preparation: ECIV 310 or permission of instructor.

ECIV 421. Advanced Reinforced Concrete Design. 3 Units.

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. Recommended preparation: ECIV 322 and consent of instructor.

ECIV 422. Advanced Structural Steel Design. 3 Units.

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. Recommended preparation: ECIV 322.

ECIV 423. Prestressed Concrete Design. 3 Units.

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. Recommended preparation: ECIV 323 or ECIV 421 and consent of instructor.

ECIV 424. Structural Dynamics. 3 Units.

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. Recommended preparation: ECIV 321 and consent of instructor.

ECIV 425. Structural Design for Dynamic Loads. 3 Units.

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. Recommended preparation: ECIV 424.

ECIV 426. Structural Reliability. 3 Units.

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.

ECIV 430. Foundation Engineering. 3 Units.

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. Recommended preparation: ECIV 330.

ECIV 431. Special Topics in Geotechnical Engineering. 3 Units.

In situ test methods. Standard Penetration Test (SPT), Cone Penetration Test (CPT), pressuremeter, vane shear test, dilatometer, seismic methods, electromagnetic methods, and electrical methods. Geotechnical field instrumentation. Measurement of load, stress, pore pressure, and deformation in the field. Stress wave theory, pile driving analysis, pavement condition survey. Recommended preparation: ECIV 330

ECIV 432. Mechanical Behavior of Soils. 3 Units.

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. Recommended preparation: ECIV 330.

ECIV 433. Soil Dynamics. 3 Units.

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. Recommended preparation: ECIV 330 and consent of instructor.

ECIV 434. Field Instrumentation and Insitu Testing. 3 Units.

In situ test methods. Standard Penetration Test (SPT), Cone Penetration Test (CPT), pressuremeter, vane shear test, dilatometer, seismic methods, electromagnetic methods, and electrical methods. Geotechnical field instrumentation. Measurement of load, stress, pore pressure, and deformation in the field. Stress wave theory, pile driving analysis, pavement condition survey. Recommended preparation: ECIV 330.

ECIV 437. Pavement Analysis and Design. 3 Units.

Analysis and design of rigid and flexible airfield and highway pavements. Pavement evaluation and rehabilitations, overlay design. Recommended preparation: ECIV 330.

ECIV 450. Environmental Engineering Chemistry. 3 Units.

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 requisites not met permission.

ECIV 451. Infrastructure Engineering Practice. 3 Units.

Case studies presenting significant accomplishments in infrastructure engineering presented by distinguished practicing engineers. Case studies will examine the historical development of our infrastructure, assessing cultural value of our built environment, alternate infrastructure models, public empowerment, sustainability, stewardship, financing, legal issues, and concepts for future development of infrastructure systems. Students will write environmental and cultural assessments of specific infrastructure projects.

ECIV 452. Infrastructure Aging and Assessment Technologies. 4 Units.

Mechanical, thermal, and electrochemical processes that cause degradation of our built infrastructure. Reinforced concrete carbonation and freezing and thawing; fatigue, brittle fracture, and corrosion of steel; weathering of masonry; degradation of asphalt pavements; deterioration of underground systems; aging of polymer-based construction products such as sealants and coatings. Assessment technologies, including non-destructive testing and mathematical modeling. Laboratory and field experiences.

ECIV 453. Infrastructure Rehabilitation Design. 4 Units.

Rehabilitation materials and systems; mechanical, electrochemical, thermal, environmental, and aesthetic criteria for decision-making; design principles; specifications and control of construction processes; rehabilitation case studies. Application to structures, pipelines, pavements, and drainage systems.

ECIV 454. Modeling Infrastructure Systems. 4 Units.

Examination of the properties that distinguish infrastructure performance models from more traditional engineering analysis models. Infrastructure software implementation strategies. Application of existing models to problems such as water distribution systems, mass transport, pavement management, and brownfield redevelopment. Development of new models to address infrastructure performance and sustainability.

ECIV 455. Infrastructure Engineering Decision Making. 3 Units.

Aspects of decision theory applied to infrastructure systems. Review of probability and statistics, engineering economics, cost-benefit analysis, impact of social, historical, environmental and government policies on decisions. Emergency management and security considerations. Methods of project financing; asset management and asset optimization.

ECIV 456. Intelligent Infrastructure Systems. 3 Units.

Topics on smart infrastructure systems; smart materials fabrication, embedded sensing technology for infrastructure condition monitoring, the system models for infrastructural condition diagnosing and adaptive controlling, and spatial-temporal integrated infrastructure management system.

ECIV 460. Environmental Remediation. 3 Units.

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. Recommended preparation: ECIV 368 or consent of instructor.

ECIV 461. Environmental Engineering Biotechnology. 3 Units.

Process design fundamentals for biological reactors applied to environmental engineering processes, including wastewater treatment, bioremediation, and bioenergy production. Topics include mass balances, methane fermentation, fixed-growth reactors, molecular biology tools, and reactor models. Recommended preparation: ECIV 368 Environmental Engineering.

ECIV 500T. Graduate Teaching II. 0 Units.

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 560. Environmental Engineering Modeling. 3 Units.

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 Units.

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 585. Fracture Mechanics. 3 Units.

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. Recommended preparation: ECIV 405, ECIV 411 and consent of instructor.

ECIV 587. Advanced Mechanics Seminar. 3 Units.

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. Recommended preparation: ECIV 406, ECIV 420, ECIV 505 or consent of instructor.

ECIV 600T. Graduate Teaching III. 0 Units.

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. students in Civil Engineering.

ECIV 601. Independent Study. 1 - 18 Unit.

Plan B.

ECIV 611. Civil Engineering Graduate Seminar. 0 Units.

Distinguished outside speakers present current research in various topics of Civil Engineering. Graduate students also present technical papers based on thesis research.

ECIV 650. Infrastructure Project. 1 - 6 Unit.

Project based experience in the application of infrastructure engineering principles to a complex infrastructure system.

ECIV 651. Thesis M.S.. 1 - 18 Unit.

Plan A.

ECIV 660. Special Topics. 1 - 18 Unit.

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 Unit.

Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Electrical Engineering and Computer Science

Electrical Engineering and Computer Science (EECS) spans a spectrum of topics from (i) materials, devices, circuits, and processors through (ii) control, signal processing, and systems analysis to (iii) software, computation, computer systems, and networking. The EECS Department at Case Western Reserve supports four synergistic degree programs: Electrical Engineering, Computer Science, Computer Engineering, and Systems & Control Engineering. Each degree program leads to the Bachelor of Science degree at the undergraduate level. 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 & Information Sciences (i.e., computer science). We offer minors in Electrical Engineering, Computer Science (BS and BA), Computer Engineering, Systems & Control Engineering, and also in Computer Gaming, Artificial Intelligence (AI), and Electronics. For supplemental information to this bulletin as well as the latest updates, please visit the EECS Department web site at <http://eeecs.case.edu>.

EECS is at the heart of modern technology. EECS disciplines are responsible for the devices and microprocessors powering our computers and embedded into everyday devices, from cell phones and tablets to automobiles and airplanes. Healthcare is increasingly building on EECS technologies: micro/nano systems, electronics/instrumentation, implantable systems, wireless medical devices, surgical robots, imaging, medical informatics, bioinformatics, system biology, and data mining and visualization. The future of energy will be profoundly impacted by EECS technologies, from smart appliances connected to the Internet, smart buildings that incorporate distributed sensing and control, to the envisioned smart grid that must be controlled, stabilized, and kept secure over an immense network. EECS drives job creation and starting salaries in our fields are consistently ranked in the top of all college majors. Our graduates work in cutting-edge companies--from giants to start-ups, in a variety of technology sectors, including computer and internet, healthcare and medical devices, manufacturing and automation, automotive and aerospace, defense, finance, energy, and consulting.

Department Structure

EECS at Case Western Reserve is organized internally into two informal divisions: (i) Computer Science (CS); and (ii) Electrical, Computer, and Systems Engineering (ECSE). The chair of EECS is Professor Kenneth Loparo.

Educational Philosophy

The EECS department is dedicated to developing high-quality graduates who will take positions of leadership as their careers advance. We recognize that the increasing role of technology in virtually every facet of our society, life, and culture makes it vital that our students have access to progressive and cutting-edge higher education programs. The program values for all of the degree programs in the department are:

- mastery of fundamentals
- creativity
- social awareness

- leadership skills
- professionalism

Stressing excellence in these core values helps to ensure that our 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.

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 and computer science, including recent developments in the field. Because of the rapid pace of advancement in these fields, our degree programs emphasize a broad and foundational science and technology background that equips students for future developments. 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.

Research

The research thrusts of the Electrical Engineering and Computer Science department include:

1. Micro/Nano Systems
2. Electronics and Instrumentation
3. Robotics and Haptics
4. Embedded Systems, including VLSI, FPGA
5. Hardware Algorithms, Hardware Security, Testing/Verification
6. Bioinformatics and Systems Biology
7. Machine Learning and Data Mining
8. Computer Networks and Distributed Systems
9. Secure and Reliable Software
10. Energy Systems, including Wind and Power Grid Management/Control
11. Gaming, Simulation, Optimization
12. Medical Informatics and Wireless Health

EECS participates in a number of groundbreaking collaborative research and educational programs, including the Microelectromechanical Systems Research Program, the Center for Computational Genomics, graduate program in Systems Biology and Bioinformatics, the Clinical & Translational Science Collaborative, the Great Lakes Energy Institute, and the VA Center for Advanced Platform Technology.

Electrical Engineering (p. 57) | Systems and Control Engineering (p. 59) | Computer Engineering (p. 60) | Computer Science (p. 61) | Suggested Programs of Study (p. 63)

Undergraduate Programs

The EECS department engineering offers accredited programs leading to BS degrees in:

1. Electrical Engineering
2. Systems and Control Engineering
3. Computer Engineering
4. Computer Science

These programs provide students with a strong background in the fundamentals of mathematics, science, and engineering. Students can use their technical and open electives to pursue concentrations in bioelectrical engineering, complex systems, automation and control, digital systems design, embedded systems, micro/nano systems, robotics and intelligent systems, signal processing and communications, and software engineering. In addition to an excellent technical education, all students in the department are exposed to societal issues, ethics, professionalism, and have the opportunity to develop leadership and creativity skills.

The Bachelor of Science degree programs in Computer Engineering, Electrical Engineering, and Systems and Control Engineering are accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

The Bachelor of Science degree program in Computer Science is accredited by the Computing Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

Electrical Engineering

The Bachelor of Science program in electrical engineering provides our students with a broad foundation in electrical engineering through combined classroom and laboratory work, and prepares our students for entering the profession of electrical engineering, as well as for further study at the graduate level.

The educational mission of the electrical engineering program 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 that will advance the general field of electrical engineering.

Program Educational Objectives

1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.
2. Graduates will use continuous learning opportunities to improve and enhance their professional skills.
3. Graduates will demonstrate leadership in their profession.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Electrical Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively

- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Core courses provide our students with a strong background in signals and systems, computers, electronics (both analog and digital), and semiconductor devices. Students are required to develop depth in at least one of the following technical areas: electromagnetics, signals and systems, solid state, computer hardware, computer software, control, and circuits. Each electrical engineering student must complete the following requirements.

Major in Electrical Engineering

Major Requirements

EECS 245	Electronic Circuits	4
EECS 246	Signals and Systems	4
EECS 281	Logic Design and Computer Organization	4
EECS 309	Electromagnetic Fields I	3
EECS 313	Signal Processing	3
EECS 321	Semiconductor Electronic Devices	4
EECS 398	Engineering Projects I	4
EECS 399	Engineering Projects II	3

Eighteen hours of approved technical electives including at least 9 hours of approved courses to constitute a depth of study

Breadth Requirement

ENGR 131	Elementary Computer Programming	3
ENGR 210	Introduction to Circuits and Instrumentation	4
EECS 281	Logic Design and Computer Organization	4
EECS 245	Electronic Circuits	4
EECS 246	Signals and Systems	4
EECS 309	Electromagnetic Fields I	3
EECS 313	Signal Processing	3
STAT 332	Statistics for Signal Processing	3
EECS 321	Semiconductor Electronic Devices	4
EECS 398	Engineering Projects I	4
EECS 399	Engineering Projects II	3

Total Units 39

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. This depth requirement may be met using a combination of the above core courses and a selection of open and technical electives.

Area I: Signals & Systems

EECS 246	Signals and Systems	4
EECS 313	Signal Processing	3

EECS 351	Communications and Signal Analysis	3
EECS 354	Digital Communications	3

Area II: Computer Software

EECS 233	Introduction to Data Structures	4
EECS 337	Compiler Design	4
EECS 338	Introduction to Operating Systems	4
EECS 393	Software Engineering	3

Area III: Solid State

PHYS 221	Introduction to Modern Physics	3
EECS 321	Semiconductor Electronic Devices	4
EECS 322	Integrated Circuits and Electronic Devices	3
EECS 415	Integrated Circuit Technology I	3

Area IV: Control

EECS 304	Control Engineering I with Laboratory	3
EECS 346	Engineering Optimization	3
EECS 381	Hybrid Systems	3
EECS 483	Data Acquisition and Control	3

Area V: Circuits

EECS 245	Electronic Circuits	4
EBME 310	Principles of Biomedical Instrumentation	3
EECS 344	Electronic Analysis and Design	3
EECS 371	Applied Circuit Design	4
EBME 418	Electronics for Biomedical Engineering	3
EECS 426	MOS Integrated Circuit Design	3

Area VI: Computer Hardware

EECS 281	Logic Design and Computer Organization	4
EECS 301	Digital Logic Laboratory	2
EECS 314	Computer Architecture	3
EECS 315	Digital Systems Design	4
EECS 316	Computer Design	3
EECS 318	VLSI/CAD	4

Area VII: Biomedical Applications

EBME 201	Physiology-Biophysics I (and 2 of the following 4 courses)	3
EBME 310	Principles of Biomedical Instrumentation	3
EBME 320	Medical Imaging Fundamentals	3
EBME 327	Bioelectric Engineering	3
EBME 401	Biomedical Instrumentation and Signal Analysis	4

At least 10 of the 14 required Electrical Engineering courses (EECS 281, 245, 246, 309, 313, 321, 398, 399, and the 6 Technical Electives) in the Electrical Engineering BS program must be satisfied by courses from the EECS department.

Statistics Requirement

STAT 332	Statistics for Signal Processing *	3
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* STAT 333 Uncertainty in Engineering and Science may be substituted with approval of advisor

Design Requirement

EECS 398	Engineering Projects I	4
EECS 399	Engineering Projects II	3

In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in one or more of a spectrum 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 the advisor a 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 instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

Cooperative Education Program in Electrical Engineering

There are many excellent Cooperative Education (CO-OP) opportunities for electrical 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 a 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.

BS/MS Program in Electrical Engineering

The department encourages highly motivated and qualified students to apply for admission to the five-year BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for EECS 399, the second senior project). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years.

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	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
Total Units		18

Minor in Electronics

The department also offers a minor in electronics for students in the College of Arts and Sciences. This program requires the completion of 31 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	Math and Calculus Applications for Life, Managerial, and Social Sci I	4
MATH 126	Math and Calculus Applications for Life, Managerial, and Social Sci II	4
PHYS 115	Introductory Physics I	4
PHYS 116	Introductory Physics II	4
ENGR 131	Elementary Computer Programming	3
ENGR 210	Introduction to Circuits and Instrumentation	4
EECS 246	Signals and Systems	4
EECS 281	Logic Design and Computer Organization	4
Total Units		31

Systems and Control Engineering

The Bachelor of Science program in systems and control engineering provides our students with the basic concepts, analytical tools, and engineering methods which are needed 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: modeling and analysis of complex energy, environmental, and biological systems; computer control of industrial plants; developing 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 these individual contributions to achieve the overall goal of the system.

Major in Systems and Control Engineering

The mission of the Systems and Control Engineering program is to provide internationally recognized excellence for graduate and undergraduate education and research in systems analysis, design, and control. These theoretical and applied areas require cross-disciplinary tools and methods for their solution.

Program Educational Objectives

1. Graduates will have applied systems methodology to multi-disciplinary projects that include technical, social, environmental, political, and/or economic factors.
2. Graduates will use systems understanding, critical thinking and problem solving skills to analyze and design engineering systems or processes that respond to technical and societal needs as demonstrated by their measured professional accomplishments in industry, government and research.
3. Graduates will facilitate multidisciplinary projects that bring together practitioners of various engineering fields in an effective, professional, and ethical manner as demonstrated by their teamwork, leadership, communication, and management skills.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Systems and Control Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering

- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

There are four elective sequences available within the BS program in systems and control engineering curriculum that represent the breadth of the discipline:

Area: 1 Dynamic Systems, Control and Signal Processing

MATH 201	Introduction to Linear Algebra	3
EECS 351	Communications and Signal Analysis	3
EECS 381	Hybrid Systems	3
EECS 401	Digital Signal Processing	3
EECS 408	Introduction to Linear Systems	3
EECS 416	Convex Optimization for Engineering	3
EECS 452	Random Signals	3
EECS 483	Data Acquisition and Control	3
EECS 489	Robotics I	3

Area 2: Systems Biology and Complex Systems Analysis

MATH 201	Introduction to Linear Algebra	3
EECS 381	Hybrid Systems	3
EECS 391	Introduction to Artificial Intelligence	3
EECS 396	Independent Projects	1 - 6
EECS 408	Introduction to Linear Systems	3
EECS 416	Convex Optimization for Engineering	3
BIOL 325	Cell Biology	3
BIOL 250	Introduction to Cell and Molecular Biology Systems	3

Area 3: Manufacturing, Robotics and Operational Systems

EECS 350/450	Operations and Systems Design	3
EECS 360/460	Manufacturing and Automated Systems	3
EECS 489	Robotics I	3
OPMT 450	Project Management	3
OPMT 420	Six Sigma and Quality Management	3

OPMT 476	Strategic Sourcing	3
OPMT 477	Enterprise Resource Planning in the Supply Chain	3

Area 4: Information Systems

EECS 233	Introduction to Data Structures	4
EECS 325	Computer Networks I	3
EECS 381	Hybrid Systems	3
EECS 391	Introduction to Artificial Intelligence	3
EECS 484	Computational Intelligence I: Basic Principles	3
EECS 491	Artificial Intelligence: Probabilistic Graphical Models	3

Cooperative Education Program in Systems and Control Engineering

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.

BS/MS Program in Systems and Control Engineering

The department encourages highly motivated and qualified students to apply for admission to the five-year BS/MS Program in the junior year. This integrated program, which permits up to 9 credit hours of graduate level coursework to be counted towards both BS and MS degree requirements (including an option to substitute MS thesis work for EECS 399, the second senior project). It also offers the opportunity to complete both the Bachelor of Science in Engineering and Master of Science degrees within five years.

Minor 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 9 credit hours must be selected from:

EECS 246	Signals and Systems	4
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 (see the EECS web page for the current responsible faculty member (<http://engineering.case.edu/eecs>)) in charge of the minor program in the Systems and Control Program. A list of suggested EECS courses to complete the minor is:

EECS 324	Modeling and Simulation of Continuous Dynamical Systems	3
EECS 313	Signal Processing	3
EECS 350	Operations and Systems Design	3
EECS 360	Manufacturing and Automated Systems	3

Computer Engineering

The Bachelor of Science program in Computer Engineering is designed to give a student a strong background in the fundamentals of computer engineering through combined classroom and laboratory work. A graduate of this program will be able to use these fundamentals to analyze and evaluate computer systems, both hardware and software. A computer engineering graduate would also be able to design and implement a computer system for general purpose or embedded computing incorporating state-of-the-art solutions to a variety of computing problems. This includes systems which have both hardware and software component, whose design requires a well-defined interface between the two, and the evaluation of the associated trade-offs.

The educational mission of the computer engineering program is to graduate students who have fundamental technical knowledge of their profession along with requisite technical breadth and communications skills to become leaders in creating the new techniques and technologies which will advance the general field of computer engineering. Core courses provide our students with a strong background in digital systems design, computer organization, hardware architecture, and digital electronics.

Program Educational Objectives

1. Graduates will be successful professionals obtaining positions appropriate to their background, interests, and education.
2. Graduates will engage in life-long learning to improve and enhance their professional skills.
3. Graduates will demonstrate leadership in their profession using their knowledge, communication skills, and engineering ability.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Computer Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Major in Computer Engineering

Major Requirements

EECS 132	Introduction to Programming in Java	3
ENGR 210	Introduction to Circuits and Instrumentation	4
EECS 233	Introduction to Data Structures	4
EECS 281	Logic Design and Computer Organization	4
EECS 301	Digital Logic Laboratory	2
EECS 302	Discrete Mathematics	3
EECS 314	Computer Architecture	3
EECS 315	Digital Systems Design	4
EECS 337	Compiler Design	4
One of the following:		4
EECS 318	VLSI/CAD	
EECS 338	Introduction to Operating Systems	

Statistics Requirement

One Statistics elective may be chosen from:

STAT 312	Basic Statistics for Engineering and Science	3
STAT 313	Statistics for Experimenters	3
STAT 332	Statistics for Signal Processing	3
STAT 333	Uncertainty in Engineering and Science	3

Design Requirement

EECS 398	Engineering Projects I	4
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In consultation with a faculty advisor, a student completes the program by selecting technical and open elective courses that provide in-depth training in principles and practice of computer engineering. With the approval of the advisor a student may emphasize a specialty of his/her choice by selecting elective courses from other programs or departments.

Many courses have integral or associated laboratories in which students gain "hands-on" experience with computer engineering principles and instrumentation. Students have ready access to the teaching laboratory facilities and are encouraged to use them during nonscheduled hours in addition to the regularly scheduled laboratory sessions. Opportunities also exist for undergraduate student participation in the wide spectrum of research projects being conducted in the department.

Cooperative Education Program in Computer Engineering

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.

BS/MS Program in Computer Engineering

Highly motivated and qualified students are encouraged to apply to the BS/MS Program which will allow them to get both degrees in five years. The BS 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.

Minor in Computer Engineering

The department also offers a 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	4
EECS 233	Introduction to Data Structures	4

Students should note that EECS 132 Introduction to Programming in Java is a prerequisite for EECS 233 Introduction to Data Structures.

The two-course hardware sequence is:

EECS 314	Computer Architecture	3
EECS 315	Digital Systems Design	4

The corresponding two-course software sequence is:

EECS 337	Compiler Design	4
EECS 338	Introduction to Operating Systems	4

In addition to these two standard sequences, a student may design his/her own depth area 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.

Computer Science

Bachelor of Science in 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 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-offs. In addition to these program specific objectives, all students in the Case School of Engineering are exposed to societal issues, professionalism, and are provided opportunities to develop leadership skills.

Our mission 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 the field of computer science.

Program Educational Objectives

1. To educate and train students in the fundamentals of computer science and mathematics, in order to analyze and solve computing problems, **as demonstrated by their professional accomplishments** in industry, government and graduate programs and measured within three to five years after graduation.
2. To educate students with an understanding of real-world computing needs, as demonstrated by their ability to address technical issues

involving computing problems encountered in industry, government and graduate programs and measured within three to five years after graduation.

- To train students to work effectively, professionally and ethically in computing-related professions, as demonstrated by their communications, teamwork and leadership skills in industry, government and graduate programs and measured within three to five years after graduation.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Computer Science is designed so that students attain:

- An ability to apply knowledge of computing and mathematics appropriate to the discipline
- An ability to analyze a problem, and identify and define the computing requirements appropriate to its solution
- An ability to design, implement, and evaluate a computer-based system, process, component, or program to meet desired needs
- An ability to function effectively on teams to accomplish a common goal
- An understanding of professional, ethical, and social responsibilities
- An ability to communicate effectively
- An ability to analyze the impact of computing on individuals, organizations, and society, including ethical, legal, security, and global policy issues
- Recognition of the need for and an ability to engage in continuing professional development
- An ability to use current techniques, skills, and tools necessary for computing practice
- An ability to apply mathematical foundations, algorithmic principles, and computer science theory in the modeling and design of computer-based systems in a way that demonstrates comprehension of the tradeoffs involved in design choices
- An ability to apply design and development principles in the construction of software systems of varying complexity

Bachelor of Arts in Computer Science

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 less technical than the Bachelor of Science program in Computer Science. This degree is particularly suitable for students with a wide range 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 four-year period.

Cooperative Education Program in Computer Science

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.

BS/MS Program in Computer Science

Students with a grade point average of 3.2 or higher are encouraged to apply to the BS/MS Program which will allow them to get both degrees in five years. The BS 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.

Minor in Computer Science (BS or BSE)

For students pursuing a BS or BSE degree, the following three courses are required for a minor in computer science:

EECS 233	Introduction to Data Structures	4
EECS 338	Introduction to Operating Systems	4
EECS 340	Algorithms	3

A student must take an additional 4 credit hours of computing courses with the exclusion of EECS 132 Introduction to Programming in Java and ENGR 131 Elementary Computer Programming. EECS 302 Discrete Mathematics may be used in place of three of these credit hours since it is a prerequisite for EECS 340 Algorithms. Students should note that EECS 132 Introduction to Programming in Java is a prerequisite for EECS 233 Introduction to Data Structures.

Minor in Computer Science (BA)

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

EECS 132	Introduction to Programming in Java	3
EECS 233	Introduction to Data Structures	4
MATH 125	Math and Calculus Applications for Life, Managerial, and Social Sci I	4

Two additional computing courses are also required for this minor.

Minor in Computer Gaming (CGM)

The minor is 16 hours as follows:

EECS 233	Introduction to Data Structures	4
EECS 324	Modeling and Simulation of Continuous Dynamical Systems	3
EECS 366	Computer Graphics	3
EECS 390	Advanced Game Development Project	3
EECS 391	Introduction to Artificial Intelligence	3

The open elective in the spring of the first year is strongly recommended to be EECS 290 Introduction to Computer Game Design and Implementation. In addition, it is recommended that one additional open elective be a "content creation" course taken from the following areas: Art, English, or Music. Students should note that EECS 132 Introduction to Programming in Java is a prerequisite for EECS 233 Introduction to Data Structures.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Electrical Engineering

First Year	Units	
	Fall	Spring
SAGES First Year Seminar	4	
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121)	4	
Elementary Computer Programming (ENGR 131)	3	
Open elective	3	
PHED (2 half semester courses)	0	
SAGES University Seminar		3
Chemistry of Materials (ENGR 145)	4	
General Physics I - Mechanics (PHYS 121) ^b	4	
Calculus for Science and Engineering II (MATH 122)	4	
PHED (2 half semester courses)		0
Year Total:	18	15

Second Year	Units	
	Fall	Spring
General Physics II - Electricity and Magnetism (PHYS 122) ^b	4	
Calculus for Science and Engineering III (MATH 223)	3	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
Logic Design and Computer Organization (EECS 281)	4	
SAGES University Seminar		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)	4	
Elementary Differential Equations (MATH 224)	3	
Electronic Circuits (EECS 245)	4	
Electromagnetic Fields I (EECS 309)	3	
Year Total:	15	17

Third Year	Units	
	Fall	Spring
HM/SS elective ^a	3	
Statistics for Signal Processing (STAT 332) ^c	3	
Statics and Strength of Materials (ENGR 200)	3	
Signals and Systems (EECS 246)	4	
Approved technical elective ^d	3	
HM/SS elective ^a		3
Semiconductor Electronic Devices (EECS 321)	4	
Applied Statistics Req. ^e		3
Approved technical elective ^d		3
Approved technical elective ^d		3
Year Total:	16	16

Fourth Year	Units	
	Fall	Spring
HM/SS elective ^a	3	

Engineering Projects I (EECS 398) ^f	4	
Open elective	3	
Professional Communication for Engineers (ENGL 398)	2	
Professional Communication for Engineers (ENGR 398)	1	
Approved technical elective ^d	3	
HM/SS elective ^a		3
Engineering Projects II (EECS 399)	3	
Approved technical elective ^d	3	
Approved technical elective ^d	3	
Open elective		3
Year Total:	16	15
Total Units in Sequence:		128

Hours Required for Graduation: 128

- a Humanities/Social Science course
- b Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.
- c Students may replace STAT 332 Statistics for Signal Processing 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 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.
- e This applied statistics requirement must utilize statistics in electrical engineering applications and is typically selected from EECS 351 Communications and Signal Analysis or EECS 313 Signal Processing. Other courses are possible with approval of advisor.
- f CO-OP students may obtain design credit for one semester of Engineering Projects 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 course instructor.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Systems and Control Engineering

First Year	Units	
	Fall	Spring
SAGES First Year Seminar	4	
Principles of Chemistry for Engineers (CHEM 111)	4	

Calculus for Science and Engineering I (MATH 121)	4	
Elementary Computer Programming (ENGR 131)	3	
Open elective	3	
PHED (2 half semester courses)	0	
SAGES University Seminar		3
General Physics I - Mechanics (PHYS 121) ^b	4	
Calculus for Science and Engineering II (MATH 122)	4	
Chemistry of Materials (ENGR 145)	4	
PHED (2 half semester courses)		0
Year Total:	18	15

Second Year**Units****Fall Spring**

General Physics II - Electricity and Magnetism (PHYS 122) ^b	4	
Calculus for Science and Engineering III (MATH 223)	3	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
Logic Design and Computer Organization (EECS 281)	4	
SAGES University Seminar		3
Elementary Differential Equations (MATH 224)		3
STAT xxx Statistical Methods Course ^c		3
Statics and Strength of Materials (ENGR 200)		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)		4
Year Total:	15	16

Third Year**Units****Fall Spring**

HM/SS elective	3	
Signals and Systems (EECS 246)	4	
Modeling and Simulation of Continuous Dynamical Systems (EECS 324)	3	
Introduction to Global Issues (EECS 342)	3	
Approved technical elective	3	
HM/SS elective		3
Control Engineering I with Laboratory (EECS 304)		3
Control Engineering I Laboratory (EECS 305)		1
Engineering Optimization (EECS 346)		3
Approved technical elective ^e		3
Open elective		4
Year Total:	16	17

Fourth Year**Units****Fall Spring**

HM/SS elective	3	
Professional Communication for Engineers (ENGL 398)	2	
Professional Communication for Engineers (ENGR 398)	1	
Engineering Economics and Decision Analysis (EECS 352)	3	
Engineering Projects I (EECS 398) ^d	4	
Approved technical elective ^f	3	

HM/SS elective		3
Engineering Projects II (EECS 399)		3
Approved technical elective ^f		3
Approved technical elective ^f		3
Approved technical elective ^f		3
Year Total:	16	15

Total Units in Sequence:**128****Hours Required for Graduation: 128**

- b Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics and PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics and PHYS 122 General Physics II - Electricity and Magnetism.
- c Choose from STAT 312 Basic Statistics for Engineering and Science, STAT 332 Statistics for Signal Processing, or STAT 333 Uncertainty in Engineering and Science.
- d CO-OP students may obtain design credit for one semester of Engineering Projects 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 course instructor.
- e Signal Processing or Communication Systems technical elective to be taken in any semester after EECS 246 Signals and Systems. This elective should be chosen from EECS 313 Signal Processing, EECS 351 Communications and Signal Analysis, or EECS 354 Digital Communications.
- f Technical electives from an approved list.

Bachelor of Science in Engineering**Suggested Program of Study: Major in Computer Engineering**

First Year	Units	
	Fall	Spring
SAGES First Year Seminar	4	
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121)	4	
Introduction to Programming in Java (EECS 132)	3	
Open elective	3	
PHED (2 half semester courses)	0	
SAGES University Seminar		3
General Physics I - Mechanics (PHYS 121)		4
Calculus for Science and Engineering II (MATH 122)		4
Chemistry of Materials (ENGR 145)		4
PHED (2 half semester courses)		0
Year Total:	18	15
Second Year	Units	
	Fall	Spring
SAGES University Seminar	3	
General Physics II - Electricity and Magnetism (PHYS 122)	4	

Calculus for Science and Engineering III (MATH 223)	3	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
Introduction to Data Structures (EECS 233)	4	
HM/SS elective		3
Elementary Differential Equations (MATH 224)	3	
Statics and Strength of Materials (ENGR 200)	3	
Logic Design and Computer Organization (EECS 281)	4	
Technical elective ^a		3
Year Total:	18	16

Third Year	Units	
	Fall	Spring
HM/SS elective	3	
Discrete Mathematics (EECS 302)	3	
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)	4	
Compiler Design (EECS 337)	4	
Technical elective ^a	3	
Professional Communication for Engineers (ENGL 398)		2
Professional Communication for Engineers (ENGR 398)		1
Digital Logic Laboratory (EECS 301)		2
Computer Architecture (EECS 314)		3
Digital Systems Design (EECS 315)		4
Introduction to Operating Systems (EECS 338) (or Technical elective,3) ^{b,a}		4
Year Total:	17	16

Fourth Year	Units	
	Fall	Spring
HM/SS elective	3	
Statistics elective ^c	3	
Technical elective ^a	3	
Technical elective (or EECS 318 VLSI/CAD) ^{a,b}	3	
Open elective	3	
HM/SS elective		3
Engineering Projects I (EECS 398) ^d		4
Technical elective ^a		3
Open elective		4
Year Total:	15	14
Total Units in Sequence:		129

Hours Required for Graduation: 129

- ^a 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.
- ^b The student must take either EECS 318 VLSI/CAD (Fall Semester) or EECS 338 Introduction to Operating Systems (Spring Semester), and a three credit hour technical elective.

^c Chosen from: 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 May be taken in the Fall semester if the student would like to take EECS 399 Engineering Projects II in the Spring semester.

Bachelor of Science**Suggested Program of Study: Major in Computer Science**

First Year	Units	
	Fall	Spring
SAGES First Year Seminar	4	
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121)	4	
Introduction to Programming in Java (EECS 132)	3	
PHED (2 half semester courses)	0	
Open elective	3	
SAGES University Seminar		3
General Physics I - Mechanics (PHYS 121)		4
Calculus for Science and Engineering II (MATH 122)		4
Chemistry of Materials (ENGR 145)		4
PHED (2 half semester courses)		0
Year Total:	18	15

Second Year	Units	
	Fall	Spring
SAGES University Seminar	3	
General Physics II - Electricity and Magnetism (PHYS 122)	4	
Calculus for Science and Engineering III (MATH 223)	3	
Logic Design and Computer Organization (EECS 281)	4	
Technical elective ^{a,b}	3	
Elementary Differential Equations (MATH 224)		3
Discrete Mathematics (EECS 302)		3
Introduction to Data Structures (EECS 233)		4
HM/SS elective		3
Technical elective ^a		3
Year Total:	17	16

Third Year	Units	
	Fall	Spring
Technical elective ^a	4	
Algorithms (EECS 340)	3	
HM/SS elective	3	
Statistics elective ^c	3	
Open elective	3	
Professional Communication for Engineers (ENGL 398)		2
Professional Communication for Engineers (ENGR 398)		1
Computer Architecture (EECS 314)		3
Introduction to Operating Systems (EECS 338)		4

Introduction to Database Systems (EECS 341)	3	
Theoretical Computer Science (EECS 343)	3	
Year Total:	16	16

Fourth Year	Units	
	Fall	Spring
Software Engineering (EECS 393)	3	
Computer Networks I (EECS 325)	3	
Technical elective ^a	3	
Technical elective ^a	3	
Open elective	3	
HM/SS elective		3
Introduction to Artificial Intelligence (EECS 391)		3
Senior Project in Computer Science (EECS 395)		4
Programming Language Concepts (EECS 345)		3
Open elective		3
Year Total:	15	16
Total Units in Sequence:		129

Hours Required for Graduation: 129

- a Chosen from the list of approved CS technical electives. All other technical electives must be approved by the student's advisor. Note that one 4-credit technical is suggested to fulfill the total credit hour graduation requirement.
- b ENGR 210 Introduction to Circuits and Instrumentation 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

Bachelor of Arts**Suggested Program of Study: Computer Science**

First Year	Units	
	Fall	Spring
SAGES First Year Seminar	4	
Math and Calculus Applications for Life, Managerial, and Social Sci I (MATH 125)	4	
Introduction to Programming in Java (EECS 132)	3	
HM/SS elective	3	
Open elective	3	
PHED (2 half semester courses)	0	
SAGES University Seminar		3
Math and Calculus Applications for Life, Managerial, and Social Sci II (MATH 126)		4
HM/SS elective		3
Open elective		3
Open elective		3
PHED (2 half semester courses)		0
Year Total:	17	16

Second Year	Units	
	Fall	Spring
SAGES University Seminar		3
Logic Design and Computer Organization (EECS 281)		4
HM/SS elective		3
Open elective		3
Open elective		3
Discrete Mathematics (EECS 302)		3
Introduction to Data Structures (EECS 233)		4
HM/SS elective		3
Open elective		3
Open elective		3
Year Total:		16

Third Year	Units	
	Fall	Spring
Professional Communication for Engineers (ENGL 398) ^c	2	
Professional Communication for Engineers (ENGR 398) ^c	1	
Technical elective ^a		4
Technical elective ^a		3
Open elective		3
Computer Architecture (EECS 314)		3
Introduction to Operating Systems (EECS 338)		4
Introduction to Database Systems (EECS 341)		3
Open elective		3
Year Total:		13

Fourth Year	Units	
	Fall	Spring
Algorithms (EECS 340)		3
Technical elective ^a		3
Open elective		3
Open elective		3
Open elective		3
Senior Project in Computer Science (EECS 395) ^b		4
Technical elective ^a		3
Open elective		3
Open elective		3
Open elective		3
Year Total:		15
Total Units in Sequence:		122

Hours Required for Graduation: 121

- a One technical elective must be a computer science course. The other two technical electives may be computer science, MATH or STAT courses. Note that one 4-credit technical is suggested to fulfill the total credit hour graduation requirement.
- b SAGES capstone course
- c SAGES Departmental Seminar

Graduate Programs

The EECS department offers graduate study leading to the Master of Science and Doctor of Philosophy degrees in (a) Electrical Engineering; (b) Computer Engineering; (c) Systems & Control Engineering; (d) Computing & Information Sciences (i.e., computer science). These graduate programs provide a balance of breadth and depth appropriate for each degree and support the department's research thrust areas by emphasizing:

Electrical Engineering

Research in microelectromechanical systems (MEMS), micro/nano sensors, solid-state and photonic devices, wireless implantable biosensors, CMOS and mixed-signal integrated circuit design, robotics, surgical robotics and simulation, and haptics.

Systems and Control Engineering

Research in non-linear control, optimization, simulation, signal processing, systems biology, smart grid, and wind energy.

Computer Engineering

Research in VLSI design, programmable logic, computer architectures, embedded systems, design for testability, reconfigurable processors, and hardware security.

Computer Science

Research in bioinformatics, databases, software engineering, data mining, machine learning, pervasive networks, distributed systems, computational biology, and medical informatics.

Incoming students are encouraged to apply for departmental teaching assistantships. In addition, training and research funds are used to provide assistantships that support the academic preparation and thesis research of graduate students. A limited number of fellowships providing partial support may also be available for students enrolled in the BS/MS program.

The department believes that the success of its graduates at all levels is due to emphasis on project and problem-oriented course material coupled with the broad-based curricular requirements.

MS students may select either Plan A which requires a research thesis or Plan B which does not require a thesis. Doctoral dissertations in all programs must be original contributions to the existing body of knowledge in engineering and science.

Academic requirements for graduate degrees in engineering are as specified by the Case School of Engineering in this bulletin (p. 3). A more detailed set of rules and regulations for each degree program contained here is available from the department, and may also be found on the department Web page (<http://engineering.case.edu/eecs>).

Graduate Certificates

Graduate Certificates are discipline independent and intended to enable knowledgeable entry into the field of study. They are prescribed 3-course, 9-credit subsets of our MS degree offerings

- **Health Informational Technology**
- **Mobility-Driven Computing**
- **Security in Computing**
- **Wearable Computing**
- **Wireless Health**
- **Wireless Health Product Development**

For more details, please refer to the [Graduate Certificate](#) information on the Case School of Engineering - San Diego website.

Master of Science - Optional Specialization

Wearable Computing

The MS degree in Electrical Engineering (EE) with a specialization in Wearable Computing may be completed as a "course-only" option program of study. Students who complete this 9-course, 27-credit course-only option will have the requisite knowledge to enter and advance the wearable computing industry.

Wireless Health

The MS degree in Electrical Engineering (EE) with a specialization in Wireless Health is a 6-course-plus-thesis, 27 credit thesis-option program of study. Students who complete this 27-credit will have the requisite knowledge to enter and advance the wireless health industry, with a greater emphasis on the technology aspects.

For more details, please refer to the Master's Degree (<http://engineering.case.edu/sandiego/msacademics>) information on the Case School of Engineering - San Diego website.

Facilities

Computer Facilities

The department computer facilities incorporate both Unix (primarily Solaris) and Microsoft Windows-based operating systems on high end computing workstations for education and research. 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 and Glennan buildings, but include Nord Hall, and are networked via the Case network.

The Case network 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. It is one of the largest fiber-to-desktop networks anywhere in the world. Every desktop has a 1 Gbps (gigabit per second) connection to a fault-tolerant 10 Gbps backbone. To complement the wired network, over 1,200 wireless access points (WAPs) are also deployed allowing anyone with a laptop or wireless enabled PDA to access resources from practically anywhere on campus.

Off campus users, through the use of virtual private network (VPN) servers, can use their broadband connections to access many on campus resources, as well as software, as if they were physically connected to the Case network. The department and the university participate in the Internet2 and National Lambda Rail projects, which provides 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 services provided through a commodity Internet connection, Case network users can take advantage of numerous online 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.

EECS faculty are active users of the Microfabrication Laboratory and participants in the Advanced Platform Technology Center described under Interdisciplinary Research Centers.

Additional Department Facilities

Sally & Larry Sears Undergraduate Design Laboratory

This laboratory supports all departmental courses in circuits and includes a state-of-the-art lecture hall, a modernistic glass-walled lab, an electronics "store", and a student lounge and meeting area. Specialized lab space is available for senior projects and sponsored undergraduate programs. The lab is open to all undergraduates, and components are provided free of charge, so students can "play and tinker" with electronics and foster innovation and creativity. The laboratory provides access to PCs, oscilloscopes, signal generators, logic analyzers, and specialized equipment such as RF analyzers and generators. In addition, the lab includes full-time staff dedicated to the education, guidance and mentoring of undergraduates in the "art and practice" of hands-on engineering.

This is the central educational resource for students taking analog, digital, and mixed-signal courses in electronics, and has been supported by various corporations in addition to alumnus Larry Sears, a successful engineer and entrepreneur. Basic workstations consist of Windows-based computers equipped with LabView software, as well as Agilent 546xx oscilloscopes, 33120A Waveform Generators, 34401A Digital Multimeters, and E3631A power supplies. Advanced workstations are similarly configured, but with a wider variety of high-performance test equipment.

Jennings Computer Center Lab

Supported by an endowment from the Jennings Foundation, this lab provides our students with the educational resources necessary for their classwork and exploration of the art of computing. This lab has both PCs and Sun Unix workstations, and includes two high-speed laser printers.

EECS Undergraduate Computer Lab

This laboratory (recently renovated with major funding provided by Rockwell Automation) on the 8th floor of the Olin building is accompanied by a suite of instructor/TA offices, and supports the freshman computing classes: ENGR 131 Elementary Computer Programming and EECS 132 Introduction to Programming in Java. Thirty student Macintosh workstations with underlying UNIX operating systems are available for hands-on instruction, and support the study of introductory programming at the university.

Nord Computer Laboratory

This is a general-purpose computer facility that is open 24 hours a day, to all students. The lab contains 50 PCs running Windows and four

Apple Macintosh computers. Facilities for color printing, faxing, copying and scanning are provided. Special software includes PRO/Engineer, ChemCAD and Visual Studio. Blank CDs, floppy disks, transparencies and other supplies are available for purchase. Visit the website (<http://www.scl.cwru.edu>) for more information.

Virtual Worlds (Gaming and Simulation) Laboratory

The Virtual Worlds Gaming and Simulation Lab forms the basis for experiential work in existing game related courses such as Artificial Intelligence, Graphics, and Simulation and for new gaming/simulation courses. Multi-disciplinary senior projects also use the lab facilities. In addition, a large number of significant cross-disciplinary immersive learning opportunities are available with the Cleveland Institute of Art, the CWRU Music department, and the CWRU School of Medicine.

The Virtual Worlds laboratory includes a PC room, a Console room, an Immersion room, an Audio room, a Medical Simulation room, and a Virtual Reality room containing:

- 24 networked high-performance Alienware gaming quality PCs
- Virtual reality components including three head mounted displays, three data gloves, a four sensor magnetic tracker, two inertial trackers, and three haptic interfaces
- Game consoles, e.g. PS2, Xbox, Gamecube, Nintendo DS, PSP
- Large screen 2-D and 3-D projection displays
- Audio and music synthesis and production equipment

Database and Bioinformatics Research Laboratory

Primarily funded by equipment grants from the National Science Foundation and Microsoft Research, this laboratory provides PCs running Windows and Linux supporting research in database systems and bioinformatics.

Networks Laboratory

Supported through donations from both Cisco Systems and Microsoft Research, the networks lab has 15 stations complete with a PC, a Cisco switch and router, IP telephony equipment, as well as network patches back to a central rack where devices at one workstation may be routed to other equipment in the lab. A "library" of related equipment is also available.

Intelligent Networks & Systems Architecting (INSA) Research Laboratory

The Intelligent Networks & Systems Architecting (INSA) Research Laboratory is a state-of-the-art research facility dedicated to intelligent computer networks, systems engineering, design, and architecting. It includes optimization, simulation, artificial intelligent, visualization, and emulation. This lab has been partially supported by NASA's Space Exploration programs for Human and Robotic Technology (H&RT). The INSA Lab is equipped with 10 high-performance workstations and 2 servers in a mixed Windows and Linux environment, with over 40 installed network interface cards providing connectivity to its wired and wireless research networks. It includes software packages such as GINO and LINDO, Arena simulation, ns2 and OPNET, as well as the STK satellite toolkit, artificial neural network, systems architecting and modeling, and statistical analysis and data management packages such as SPSS. The INSA Lab is also used for research in heterogeneous,

sensor web, and mobile ad-hoc networks with space and battlefield applications.

VLSI Design Laboratory

This lab has been supported by the Semiconductor Research Corporation, NSF, NASA, Synopsys and Sun Microsystems. This laboratory has a number of advanced UNIX workstations that run commercial CAD software tools for VLSI design and is currently used to develop design and testing techniques for embedded system-on-chip.

Embedded Systems Laboratory

The Embedded Systems Laboratory is equipped with several Sun Blade Workstations running Solaris and Intel PCs running Linux. This lab has been recently equipped with advanced FPGA Virtex II prototype boards from Xilinx, including about 100 Xilinx Virtex II FPGAs and Xilinx CAD tools for development work. A grant-in-aid from Synopsys has provided the Synopsys commercial CAD tools for software development and simulation. This Lab is also equipped with NIOS FPGA boards from Altera, including software tools.

Mixed-Signal Integrated Circuit Laboratory

This research laboratory includes a cluster of Windows workstations and a UNIX server with integrated circuit design software (Cadence Custom IC Bundle), as well as a variety of equipment used in the characterization of mixed-signal (analog and digital) integrated circuits, which are typically fabricated using the MOSIS foundry service. Test equipment includes an IC probe station, surface-mount soldering equipment, logic and network/spectrum analyzers, an assortment of digital oscilloscopes with sample rates up to 1 GHz, and a variety of function generators, multi-meters, and power supplies.

Microelectromechanical Systems (MEMS) Research Laboratory

The MEMS Research Laboratory is equipped for microfabrication processes that do not require a clean room environment. These include chemical-mechanical polishing (two systems), bulk silicon etching, aqueous chemical release of free standing micromechanical components, and supercritical point drying. In addition to the fabrication capabilities, the lab is also well equipped for testing and evaluation of MEMS components as it houses wafer-scale probe stations, a vacuum probe station, a multipurpose vacuum chamber, and an interferometric load-deflection station. Two large (8 x 2 ft²) vibration isolated air tables are available for custom testing setups. The laboratory has a wide variety of electronic testing instruments, including a complete IV-CV testing setup.

BioMicroSystems Laboratory

This research laboratory focuses on developing wireless integrated circuits and microsystems for a variety of applications in biomedical and neural engineering. The laboratory contains several PC computers, software packages for design, simulation, and layout of high-performance, low-noise, analog/mixed-signal/RF circuits and systems, and testing/measurement equipment such as dc power supply, arbitrary function generator, multichannel mixed-signal oscilloscope, data acquisition hardware, spectrum analyzer, potentiostat, and current source meter. Visit the website (<http://www.mohsenlab-cwru.org>) for more information.

Emerging Materials Development and Evaluation Laboratory

The EMDE Laboratory is equipped with tooling useful in characterizing materials for MEMS applications. The laboratory contains a PC-based apparatus for load-deflection and burst testing of micromachined membranes, a custom-built test chamber for evaluation and reliability testing of MEMS-based pressure transducers and other membrane-based devices, a probe station for electrical characterization of micro-devices, a fume hood configured for wet chemical etching of Si, polymers, and a wide variety of metals, tooling for electroplating, an optical reflectometer, and a supercritical-point dryer for release of surface micromachined devices. The lab also has a PC with layout and finite element modeling software for device design, fabrication process design and analysis of testing data.

Laboratory for Nanoscale Devices and Integrated Systems

This research lab explores new engineering and physics at the nanoscale, and by applying such knowledge, develops new devices and tools for emerging technological applications in the new frontiers of information, biomedical, and life sciences. A primary current theme of the research is on developing nanoscale electromechanical systems (NEMS), based on exploration and understandings of mesoscopic devices fundamentals and new characteristics of various nanoscale structures and functional systems. The lab has been developing NEMS with new functions and high performance, in combination with some of the latest advances in advanced materials, integrated circuits, and others, through crossdisciplinary explorations and collaboration. The lab is dedicated to the development of various NEMS transducers, biosensors, high-frequency nanodevices, and high-precision instruments. For more information, contact Dr. Philip Feng (philip.feng@case.edu).

Some of the recent research highlights include: the first very-high-frequency silicon nanowire resonators and sensors, the first ultra-high-frequency self-sustaining oscillators (aka NEMS clocks), the first low-voltage (~1V), high-speed nanowire NEMS switches, and the first NEMS mass sensors for weighing single-biomolecules and for probing the noise arising from adsorbed atoms walking on the surface of a vibrating NEMS.

Control and Energy Systems Center (CESC)

The Control and Energy Systems Center (CESC) looks for new transformational research and engineering breakthroughs to build a better world, improving our industry, economy, energy, environment, water resources and society, all with sustainability and within an international collaboration framework. With an interdisciplinary and concurrent engineering approach, the CESC focuses on bridging the gap between fundamental and applied research in advanced control and systems engineering, with special emphasis in energy innovation, wind energy, power systems, water treatment plants, sustainability, spacecraft, environmental and industrial applications. Fundamental research foci are to gain knowledge and understanding on multi-input-multi-output physical worlds, nonlinear plants, distributed parameter systems, plants with non-minimum phase, time delay and/or uncertainty, etc., and to develop new methodologies to design quantitative robust controllers to improve the efficiency and reliability of such systems. Applied research aims to develop advanced solutions with industrial partners, for practical control engineering problems in energy systems, multi-megawatt wind turbines, renewable energy plants, power system dynamics and control, grid integration, energy storage, power electronics, wastewater treatment plants, desalination systems, formation flying

spacecraft, satellites with flexible appendages, heating systems, robotics, parallel kinematics, telescope control, etc. The Center was established in 2009 with the support of the Milton and Tamar Maltz Family Foundation and the Cleveland Foundation.

Process Control Laboratory

This laboratory contains process control pilot plants and computerized hardware for data acquisition and process control that is used for demonstrations, teaching, and research. This laboratory also has access to steam and compressed air for use in the pilot processes that include systems for flow and temperature control, level and temperature control, pH control, and pressure control plants.

Dynamics and Control Laboratory

This laboratory contains data acquisition and control devices, PLCs, electromechanical systems, and mechanical, pneumatic, and electrical laboratory experiments for demonstrations, teaching, and research. Particular systems include: AC/DC servo systems, multi-degree-of-freedom robotic systems, rectilinear and torsional multi-degree-of-freedom vibration systems, inverted pendulum, magnetic levitation system, and a PLC-controlled low-voltage AC smart grid demonstration system that includes conventional and renewable (wind and solar) generation, battery and compressed air energy storage, residential, commercial and industry loads, a capacitor bank for real-time power factor correction, and advanced sensing and controls implemented through an interconnected system of intelligent software agents.

Electrical, Computer, and Systems Engineering Division

Kenneth A. Loparo, PhD
(Case Western Reserve University)

Nord Professor of Engineering and Chair of EECS

Stability and control of nonlinear and stochastic systems; fault detection, diagnosis, and prognosis; recent applications work in advanced control and failure detection of rotating machines, signal processing for the monitoring and diagnostics of physiological systems, and modeling, analysis, and control of power and energy systems

Swarup Bhunia, PhD
(Purdue University)

T. and A. Schroeder Associate Professor

Low power and robust nanoelectronics, adaptive nanocomputing, hardware security and protection, implantable electronics

Marc Buchner, PhD
(Michigan State University)

Associate Professor

Computer gaming and simulation, virtual reality, software-defined radio, wavelets, joint time-frequency analysis

M. Cenk Cavusoglu, PhD
(University of California, Berkeley)

Professor

Robotics, systems and control theory, and human-machine interfaces; with emphasis on medical robotics, haptics, virtual environments, surgical simulation, and bio-system modeling and simulation

Vira Chankong, PhD
(Case Western Reserve University)

Associate Professor

Large-scale optimization; logic-based optimization; multi-objective optimization; optimization applications in radiation therapy treatment planning, medical imaging, manufacturing and production systems, and engineering design problems

Philip Feng, PhD
(California Institute of Technology)

Assistant Professor

Nanoelectromechanical systems (NEMS), energy-efficient devices, advanced materials & devices engineering, bio/chemical sensors & biomedical microsystems, RF/microwave devices & circuits, low-noise measurement & precision instruments

Mario Garcia-Sanz, DrEng
(University of Navarra, Spain)

Milton and Tamar Maltz Professor in Energy Innovation

Robust and nonlinear control, quantitative feedback theory, multivariable control, dynamic systems, systems modeling and identification; energy innovation, wind energy, spacecraft, electrical, mechanical, environmental and industrial applications

Evren Gurkan-Cavusoglu, PhD
(Middle East Technical University)

Assistant Professor

Systems and control theory, systems biology, computational biology, biological system modeling, signal processing applied to biological systems, signal processing

Mingguo Hong, PhD
Associate Professor

Power systems, electricity markets, operation research, optimization, smart grid

Gregory S. Lee, PhD
(University of Washington)

Assistant Professor

Haptic devices, including low-power design and effects on perception; applications to robotic surgery and telesurgery; secure teleoperation

Wei Lin, PhD
(Washington University in St. Louis)

Professor

Nonlinear control, dynamic systems and homogeneous systems theory, H-infinity and robust control, adaptive control, system parameter estimation and fault detection, nonlinear control applications to under-actuated mechanical systems, biologically-inspired systems and systems biology

Behnam Malakooti, PhD, PE
(Purdue University)

Professor

Design and multi-objective optimization, manufacturing/production/operations systems, intelligent systems and networks, artificial neural networks, biological systems, intelligent decision making

Mehran Mehregany, PhD
(Massachusetts Institute of Technology)
Goodrich Professor of Engineering Innovation
Research and development at the intersections of micro/nano-electro-mechanical systems, semiconductor silicon carbide and integrated circuits

Francis "Frank" L. Merat, PhD, PE
(Case Western Reserve University)
Associate Professor
Computer and robot vision, digital image processing, sensors, titanium capacitors and power electronics; RF and wireless systems; optical sensors; engineering education

Pedram Mohseni, PhD
(University of Michigan)
Associate Professor
Biomedical microsystems, bioelectronics, wireless neural interfaces, CMOS interface circuits for MEMS, low-power wireless sensing/actuating microsystems

Wyatt S. Newman, PhD, PE
(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, mobile robotic platforms

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

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

Sree N. Sreenath, PhD
(University of Maryland)
Professor
Systems biology complexity research (modeling, structural issues, and simulation); cell signaling, population behavior, and large-scale behavior; global issues and sustainable development

Hongping Zhao, PhD
(Lehigh University)
Assistant Professor
Applied physics of semiconductor optoelectronics materials and devices, physics of semiconductor nanostructures, and semiconductors for light emitting diodes, lasers, and energy applications; emphasis on III-Nitride semiconductors

Christian A. Zorman, PhD
(Case Western Reserve University)
Professor
Materials and processing techniques for MEMS and NEMS, wide bandgap semiconductors, development of materials and fabrication techniques for polymer-based MEMS and bioMEMS

Computer Science Division

Harold S. Connamacher, PhD
(University of Toronto)
Assistant Professor
Constraint satisfaction problems, graph theory, random structures, and algorithms

Chris Fietkiewicz, PhD
(Case Western Reserve University)
Assistant Professor
Applied and theoretical neuroscience, neuronal modeling, signal processing and signal analysis, electrophysiology, applications to epilepsy and respiratory control

Mehmet Koyuturk, PhD
(Purdue University)
T. & D. Schroeder Associate Professor of Computer Science and Engineering
Bioinformatics and computational biology, computational modeling and algorithm development for systems biology, integration, mining and analysis of biological data, algorithms for distributed systems

Michael Lewicki, PhD
(California Institute of Technology)
Associate Professor
Computational perception and scene analysis, visual representation and processing, auditory representation and analysis

Jing Li, PhD
(University of California, Riverside)
Associate Professor
Computational biology and bioinformatics, statistical genomics and functional genomics, systems biology, algorithms

Vincenzo Liberatore, PhD
(Rutgers University)
Associate Professor
Distributed systems, Internet computing, randomized algorithms

Gultekin Ozsoyoglu, PhD
(University of Alberta, Canada)
Professor
Graph databases and data mining problems in metabolic networks, metabolomics, and systems biology, bioinformatics, web data mining

Z. Meral Ozsoyoglu, PhD
(University of Alberta, Canada)
Andrew R. Jennings Professor of Computing
Database systems, database query languages and optimization, data models, index structures, bioinformatics, medical informatics

H. Andy Podgurski, PhD
(University of Massachusetts, Amherst)
Professor
Software engineering methodology and tools, especially use of data mining, machine learning, and program analysis techniques in software testing, fault detection and localization, reliable engineering and software security, electronic medical records, privacy

Michael Rabinovich, PhD
(University of Washington)
Professor
Computer networks, Internet performance evaluation, databases, utility computing

Soumya Ray, PhD
(University of Wisconsin, Madison)
Associate Professor
Artificial intelligence, machine learning, reinforcement learning, automated planning, applications to interdisciplinary problems including medicine and bioinformatics

GQ (Guo-Qiang) Zhang, PhD
(Cambridge University, England)
Professor
Programming languages, theory of computation, logic and topology in computer science, knowledge representation, information technology, clinical and medical informatics, semantic web

Xiang Zhang, PhD
(University of North Carolina at Chapel Hill)
T. and D. Schroeder Assistant Professor
Computational genetics, bioinformatics, data mining, machine learning, databases

Research Faculty

Michael Fu, PhD
(Case Western Reserve University)
Research Assistant Professor
Neuro-rehabilitation and motor-relearning, with emphasis on virtual environments, neuromuscular electrical stimulation, robotics, psychophysics, haptic interfaces, and brain-machine interfaces

Farhad Kaffashi, PhD
(Case Western Reserve University)
Research Assistant Professor
Signal processing of physiological time series data, systems and control

Joseph A. Potkay, PhD
(University of Michigan)
Research Assistant Professor
Medical microsystems, MEMS, microfluidics; microfabricated artificial organs, biocompatible sensor/actuator systems; energy harvesting and implantable power generators

Active Emeritus Faculty

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

Dov Hazony, PhD
(University of California, Los Angeles)
Emeritus Professor
Network synthesis, ultrasonics, communications

Wen H. Ko, PhD
(Case Institute of Technology)
Emeritus Professor
Solid state electronics, micro and nano sensors, biomedical instrumentation, implant telemetry

Mihajlo D. Mesarovic, PhD
(University of Belgrade)
Emeritus Professor
Complex systems theory, global issues and sustainable development, systems biology

Lee J. White, PhD
(University of Michigan)
Emeritus Professor
Software testing: regression testing, GUI testing, specification-based testing, testing of object-oriented software

Adjunct Faculty Appointments

Michael Adams, PhD
(Case Western Reserve University)
Adjunct Assistant Professor

Mark A. Allman, MSEE
(Ohio University)
Adjunct Instructor

Michael S. Branicky, ScD, PE
(Massachusetts Institute of Technology)
Adjunct Professor

Lev Gonick, Ph.D.
(York University, Toronto)
Adjunct Professor

John C. Hoag, Ph.D.
(The Ohio State University)
Adjunct Associate Professor

Reza Jamesebi, PhD
(Case Western Reserve University)
Adjunct Assistant Professor

Suparerk Janjarasjitt, PhD
(Case Western Reserve University)
Adjunct Assistant Professor

John R. Miller, Ph.D.
(Massachusetts Institute of Technology)
Adjunct Professor

Srinivas Raghavan, PhD
(Ohio State University)
Adjunct Professor

Gideon Samid, PhD
(Israel Institute of Technology)
Adjunct Assistant Professor

Shivakumar Sastry, PhD
(Case Western Reserve University)
Adjunct Associate Professor

William L. Schultz, PhD, PE
(Case Western Reserve University)
Adjunct Associate Professor

Marvin S. Schwartz, PhD
(Case Western Reserve University)
Adjunct Professor

Larry Sears
(Case Western Reserve University)
Adjunct Instructor

Amit Sinha, PhD
(Case Western Reserve University)
Adjunct Assistant Professor

Benjamin D. Smith, DMA
(University of Illinois at Urbana-Champaign)
Adjunct Instructor

Norman Tien, PhD
(University of California, San Diego)
Adjunct Professor

Peter J. Tsivitse, PhD
(Case Western Reserve University)
Adjunct Professor

Stephen D. Umans, PhD
(Massachusetts Institute of Technology)
Adjunct Professor

Francis G. Wolff, Ph.D.
(Case Western Reserve University)
Adjunct Associate Professor

Olaf Wolkenhauer, PhD
(UMIST, Manchester)
Adjunct Professor

Qing-rong Jackie Wu, PhD
(Mayo Graduate School)
Adjunct Associate Professor

Secondary Faculty Appointments

Alexis R. Abramson, PhD
(University of California, Berkeley)
Associate Professor, Mechanical and Aerospace Engineering

Gurkan Bebek, Ph.D.
(Case Western Reserve University)
Secondary Instructor

Dominique Durand, Ph.D.
(University of Toronto)
Secondary Professor

Mark Griswold, PhD
(University of Würzburg, Germany)
Professor, Radiology

Thomas LaFramboise, PhD
(University of Illinois)
Associate Professor, Genetics

Anant Madabhushi, Ph.D.
(University of Pennsylvania)
Secondary Associate Professor

Roger D. Quinn, PhD
(Virginia Polytechnic Institute and State University)
Professor, Mechanical and Aerospace Engineering

Satya S. Sahoo, PhD
(Wright State University)
Assistant Professor, Center for Clinical Investigations

Nicole Sieberlich, PhD
(University of Würzburg, Germany)
Assistant Professor, Biomedical Engineering

Xiong (Bill) Yu, PhD, PE
(Purdue University)
Associate Professor, Civil Engineering

Courses

EECS 132. Introduction to Programming in Java. 3 Units.

Introduction to computer programming and problem solving with the Java language. Computers, operating systems, and Java applications; software development; conditional statements; loops; methods; arrays; classes and objects; object-oriented design; unit testing; strings and text I/O; inheritance and polymorphism; GUI components; application testing; abstract classes and interfaces; exception handling; files and streams; GUI event handling; generics; collections; threads; comparison of Java to C, C++, and C#.

EECS 233. Introduction to Data Structures. 4 Units.

The programming language Java; pointers, files, 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. Prereq: EECS 132.

EECS 245. Electronic Circuits. 4 Units.

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. Prereq or Coreq: MATH 224.

EECS 246. Signals and Systems. 4 Units.

Mathematical representation, characterization, and analysis of continuous-time signals and systems. Development of elementary mathematical models of continuous-time dynamic systems. Time domain and frequency domain analysis of linear time-invariant systems. Fourier series, Fourier transforms, and Laplace transforms. Sampling theorem. Filter design. Introduction to feedback control systems and feedback controller design. Prereq: ENGR 210. Prereq or Coreq: MATH 224.

EECS 251. Numerical Methods. 3 Units.

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: MATH 122 and either ENGR 131 or EECS 132.

EECS 281. Logic Design and Computer Organization. 4 Units.

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 or EECS 132.

EECS 290. Introduction to Computer Game Design and Implementation. 3 Units.

This class begins with an examination of the history of video games and of game design. Games will be examined in a systems context to understand gaming and game design fundamentals. Various topics relating directly to the implementation of computer games will be introduced including graphics, animation, artificial intelligence, user interfaces, the simulation of motion, sound generation, and networking. Extensive study of past and current computer games will be used to illustrate course concepts. Individual and group projects will be used throughout the semester to motivate, illustrate and demonstrate the course concepts and ideas. Group game development and implementation projects will culminate in classroom presentation and evaluation. Prereq: EECS 132.

EECS 293. Software Craftsmanship. 4 Units.

A course to improve programming skills, software quality, and the software development process. Software design; Version control; Control issues and routines; Pseudo-code programming process and developer testing; Defensive programming; Classes; Debugging; Self-documenting code; Refactoring. Prereq: EECS 233.

EECS 296. Independent Projects. 1 - 3 Unit.

Independent projects in Computer Engineering, Computer Science, Electrical Engineering and Systems and Control Engineering. Recommended preparation: ENGR 131 or EECS 132. Prereq: Limited to freshmen and sophomore students.

EECS 297. Special Topics. 1 - 3 Unit.

Special topics in Computer Engineering, Computer Science, Electrical Engineering, and Systems and Control Engineering. Prereq: Limited to freshmen and sophomores.

EECS 301. Digital Logic Laboratory. 2 Units.

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 Machines, register based design, and arithmetic computational blocks. Prereq: EECS 281.

EECS 302. Discrete Mathematics. 3 Units.

A general introduction to basic mathematical terminology and the techniques of abstract mathematics in the context of discrete mathematics. Topics introduced are mathematical reasoning, Boolean connectives, deduction, mathematical induction, sets, functions and relations, algorithms, graphs, combinatorial reasoning. Offered as EECS 302 and MATH 304. Prereq: MATH 122 or MATH 124 or MATH 126.

EECS 304. Control Engineering I with Laboratory. 3 Units.

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. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246 or equivalent.

EECS 305. Control Engineering I Laboratory. 1 Unit.

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. Coreq: EECS 304.

EECS 309. Electromagnetic Fields I. 3 Units.

Maxwell's integral and differential equations, boundary conditions, constitutive relations, energy conservation and Poynting 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: PHYS 122. Prereq or Coreq: MATH 224.

EECS 312. Introduction to Electric Power Systems. 3 Units.

This course is intended to be an introduction to three-phase electric power systems. Modeling of system components including generators, transformers, loads, transmission lines. The per-unit system. One-line diagrams and equivalent circuits. Real and reactive power. Phasor diagrams. Voltage and frequency regulation. Load-flow analysis. Short-circuit calculations. Fault analysis using the techniques of symmetrical component analysis.

EECS 313. Signal Processing. 3 Units.

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. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: EECS 246.

EECS 314. Computer Architecture. 3 Units.

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 Units.

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 prototyping, and switch/logic-level simulation. Prereq: EECS 281.

EECS 316. Computer Design. 3 Units.

Methodologies for systematic design of digital systems with emphasis on programmable logic implementations and prototyping. Laboratory which uses modern design techniques based on hardware description languages such as VHDL, CAD tools, and Field Programmable Gate Arrays (FPGAs). Prereq: EECS 281 and EECS 315.

EECS 318. VLSI/CAD. 4 Units.

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. Prereq: EECS 281 and EECS 315.

EECS 319. Applied Probability and Stochastic Processes for Biology. 3 Units.

Applications of probability and stochastic processes to biological systems. Mathematical topics will include: introduction to discrete and continuous probability spaces (including numerical generation of pseudo random samples from specified probability distributions), Markov processes in discrete and continuous time with discrete and continuous sample spaces, point processes including homogeneous and inhomogeneous Poisson processes and Markov chains on graphs, and diffusion processes including Brownian motion and the Ornstein-Uhlenbeck process. Biological topics will be determined by the interests of the students and the instructor. Likely topics include: stochastic ion channels, molecular motors and stochastic ratchets, actin and tubulin polymerization, random walk models for neural spike trains, bacterial chemotaxis, signaling and genetic regulatory networks, and stochastic predator-prey dynamics. The emphasis will be on practical simulation and analysis of stochastic phenomena in biological systems. Numerical methods will be developed using both MATLAB and the R statistical package. Student projects will comprise a major part of the course. Offered as BIOL 319, EECS 319, MATH 319, BIOL 419, EBME 419, and PHOL 419. Prereq: MATH 224 or MATH 223 and BIOL 300 or BIOL 306 and MATH 201 or MATH 307 or consent of instructor.

EECS 321. Semiconductor Electronic Devices. 4 Units.

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. Prereq: PHYS 122. Prereq or Coreq: MATH 224.

EECS 322. Integrated Circuits and Electronic Devices. 3 Units.

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: PHYS 122. Prereq or Coreq: MATH 224.

EECS 324. Modeling and Simulation of Continuous Dynamical Systems. 3 Units.

This course examines the computer-based modeling and simulation of continuous dynamical system behavior in a variety of systems including electric power systems, industrial control systems, and signal processing that are represented by a set of differential equations need to be solved numerically in order to compute and represent their behavior for study. In addition to these applications, there are many other important applications of these tools in computer games, virtual worlds, weather forecasting, and population models, to name a few examples. Numerical integration techniques are developed to perform these computations. Multiple computational engines such as Matlab, Simulink, Unity, and physics engines etc. are also examined as examples of commonly used software to solve for and visualize continuous-time system behavior. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide motivation and a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Prereq: MATH 224.

EECS 325. Computer Networks I. 3 Units.

An introduction to computer networks and the Internet. Applications: http, ftp, e-mail, DNS, socket programming. Transport: UDP, TCP, reliable data transfer, and congestion control. Network layer: IP, routing, and NAT. Link layer: taxonomy, Ethernet, 802.11. Prereq: EECS 233 and Junior Standing or Instructor Consent.

EECS 326. Instrumentation Electronics. 3 Units.

A second course in instrumentation with emphasis on sensor interface electronics. General concepts in measurement systems, including accuracy, precision, sensitivity, linearity, and resolution. The physics and modeling of resistive, reactive, self-generating, and direct-digital sensors. Signal conditioning for same, including bridge circuits, coherent detectors, and a variety of amplifier topologies: differential, instrumentation, charge, and transimpedance. Noise and drift in amplifiers and resistors. Practical issues of interference, including grounding, shielding, supply/return, and isolation amplifiers. Prereq: ENGR 210 and (EECS 246, EBME 308 or EMAE 350).

EECS 337. Compiler Design. 4 Units.

Design and implementation of compilers and other language processors. Scanners and lexical analysis; regular expressions and finite automata; scanner generators; parsers and syntax analysis; context free grammars; parser generators; semantic analysis; intermediate code generation; runtime environments; code generation; machine independent optimizations; data flow and dependence analysis. There will be a significant programming project involving the use of compiler tools and software development tools and techniques. Prereq: EECS 233 and EECS 281.

EECS 338. Introduction to Operating Systems. 4 Units.

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 339. Web Data Mining. 3 Units.

Web crawling technology, web search and information extraction, unsupervised and semi-supervised learning techniques and their application to web data extraction, social network analysis, various pagerank algorithms, link analysis, web resource discovery, web, resource description framework (RDF), XML, Web Ontology Language (OWL). Prereq: EECS 338, EECS 341, and (EECS 302 or MATH 304).

EECS 340. Algorithms. 3 Units.

Fundamentals in algorithm design and analysis. Loop invariants, asymptotic notation, recurrence relations, sorting algorithms, divide-and-conquer, dynamic programming, greedy algorithms, basic graph algorithms. Prereq: EECS 233 and (EECS 302 or MATH 304).

EECS 341. Introduction to Database Systems. 3 Units.

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 and (EECS 302 or MATH 304).

EECS 342. Introduction to Global Issues. 3 Units.

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 CWRU 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 (GENle) in joint, participatory scenario analysis via the internet.

EECS 342I. Global Issues, Health, & Sustainability in India. 3 Units.

Global Issues, Health, & Sustainability in India is an interdisciplinary social work and engineering collaboration that includes a short-term cross-cultural immersion. This course brings together social work (knowledge, values, and skills) and health care (promotion, education, and community) perspectives to the understanding of technical project assessment, selection, planning and implementation in India. The course is also designed to help students understand culturally relevant community engagement strategies to ensure project acceptance in underserved and developing communities. Many field sites will be visited in order to observe first-hand the community assessment and development of projects that engineers implement. An example of these projects could include infrastructure to support green energy and water (resource planning, development, conservation, and sanitation). This study abroad course will acquaint students with history and culture of India, its social, political and economic development and the impact it has on health and the delivery of social services. Participants will learn about factors affecting the abilities to reach, treat, educate, and equip communities to improve health outcomes. Engineering students will learn the quantitative aspects using a paradigm of hierarchical systems, mathematical modeling, and scenario analysis using a 'reasoning support' system. Together the engineering, social work, and health sciences students in disciplinary-balanced teams will jointly work on real and meaningful projects marrying the descriptive scenarios (that is the 'subjective' aspect) with the numerical scenario analysis based on mathematical modeling (or 'objective' aspect) to form a coherent view of the future. The course will be taught using both lecture and experiential modalities. Engineering students will conduct computer modeling work. Along with visiting a variety of governmental and non-governmental institutions, organizations and projects, students will visit historical sites and attend cultural events. Offered as EECS 342I and SASS 375I Counts for CAS Global & Cultural Diversity Requirement.

EECS 343. Theoretical Computer Science. 3 Units.

Introduction to different classes of automata and their correspondence to different classes of formal languages and grammars, computability, complexity and various proof techniques. MATH/EECS 343 and MATH 410 cannot both be taken for credit. Offered as EECS 343 and MATH 343. Prereq: EECS 302 or MATH 304.

EECS 344. Electronic Analysis and Design. 3 Units.

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 Units.

This course examines the four main programming paradigms: imperative, object-oriented, functional, and logical. It is assumed that students will come to the course with significant exposure to object-oriented programming and some exposure to imperative programming. The course will teach the functional paradigm in depth, enhance the students' knowledge of the object-oriented and imperative paradigms, and introduce the logical paradigm. The course will explore language syntax, semantics, names/scopes, types, expressions, assignment, subprograms, abstraction and inheritance. This exploration will have several forms. Students will study the programming language concepts at a theoretical level, use the concepts in functional language programming, and implement the concepts by designing language interpreters. Prereq: EECS 233 and (EECS 302 or MATH 304).

EECS 346. Engineering Optimization. 3 Units.

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. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course. Recommended preparation: MATH 201.

EECS 350. Operations and Systems Design. 3 Units.

Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and time series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queuing models, simulation, and artificial intelligence.

EECS 351. Communications and Signal Analysis. 3 Units.

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 requisites not met permission.

EECS 352. Engineering Economics and Decision Analysis. 3 Units.

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. The course will incorporate the use of Grand Challenges in the areas of Energy Systems, Control Systems, and Data Analytics in order to provide a framework for problems to study in the development and application of the concepts and tools studied in the course. Various aspects of important engineering skills relating to leadership, teaming, emotional intelligence, and effective communication are integrated into the course.

EECS 354. Digital Communications. 3 Units.

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 246 or requisites not met permission.

EECS 359. Bioinformatics in Practice. 3 Units.

This course covers basic computational methods of organizing and analyzing biological data, targeting senior and junior level students from both mathematical/computational sciences and life sciences. The aim of the course is to provide the students with basic skills to be able to understand molecular biology data and associated abstractions (sequences, structure, gene expression, molecular network data), access to available resources (public databases, computational tools on the web). Implement basic computational methods for biological data analysis, and use understanding of these methods to solve other problems that arise in biological data analysis. Topics covered include DNA and protein sequence databases, pairwise sequence alignment and sequence search (dynamic programming, BLAST), multiple sequence alignment (HMMs, CLUSTAL-W), sequence clustering, motif finding, pattern matching, phylogenetic analysis (tree reconstruction, neighbor joining, maximum parsimony, maximum likelihood), gene finding, functional annotation, biological ontologies, analysis of gene expression data, and network biology (protein protein interactions, topology, modularity). Prereq: Junior or Senior Standing.

EECS 360. Manufacturing and Automated Systems. 3 Units.

Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as EECS 360 and EECS 460.

EECS 365. Complex Systems Biology. 3 Units.

Complex Systems Biology is an interdisciplinary course based on systems science, engineering, biology, and medicine. The objective is to provide students with an understanding of the current state of systems biology and major challenges ahead. The biological phenomena across the level of complexity will be considered from molecular to organisms and ecology to provide universality of the systems concepts for understanding the functions and behavior of biological systems. Case studies are used and a course project is required to be completed. Prereq: Junior Standing.

EECS 366. Computer Graphics. 3 Units.

Theory and practice of computer graphics: Basic elements of a computer graphics rendering pipeline. Fundamentals of input and display devices. Geometrical transformations and their matrix representations. Homogeneous coordinates, projective and perspective transformations. Algorithms for clipping, hidden surface removal, and anti-aliasing. Rendering algorithms: introduction to local and global shading models, color, and lighting models for reflection, refraction, transparency. Real-time rendering methods and animation. Prereq: EECS 233.

EECS 368. Power System Analysis I. 3 Units.

This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as EECS 368 and EECS 468. Prereq: EECS 245.

EECS 369. Power System Analysis II. 3 Units.

This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as EECS 369 and EECS 469. Prereq: EECS 368.

EECS 370. Smart Grid. 3 Units.

This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as EECS 370 and EECS 470. Prereq: EECS 368.

EECS 371. Applied Circuit Design. 4 Units.

This course will consist of lectures and lab projects designed to provide students with an opportunity to consolidate their theoretical knowledge of electronics and to acquaint them with the art and practice of circuit and product design. The lectures will cover electrical and electronic circuits and many electronic and electrical devices and applications. Examples include mixed-signal circuits, power electronics, magnetic and piezo components, gas discharge devices, sensors, motors and generators, and power systems. In addition, there will be discussion of professional topics such as regulatory agencies, manufacturing, testing, reliability, and product cost. Weekly labs will be true "design" opportunities representing real-world applications. A specification or functional description will be provided, and the students will design the circuit, select all components, construct a breadboard, and test. The objective will be functional, pragmatic, cost-effective designs. Prereq: EECS 245.

EECS 374. Advanced Control and Energy Systems. 3 Units.

This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as EECS 374 and EECS 474. Prereq: EECS 304.

EECS 375. Applied Control. 3 Units.

This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS 374 or EECS 474. Offered as EECS 375 and EECS 475. Prereq: EECS 304 or Requisites Not Met permission.

EECS 376. Mobile Robotics. 4 Units.

Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams. Prereq: ENGR 131 or EECS 233.

EECS 381. Hybrid Systems. 3 Units.

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 (EECS 246 or EECS 302 or MATH 304).

EECS 390. Advanced Game Development Project. 3 Units.

This game development project course will bring together an interdisciplinary group of advanced undergraduate students in the fields of Electrical Engineering and Computer Science, Art, Music, and English to focus on the design and development of a complete, fully-functioning computer game (as an interdisciplinary team). The student teams are given complete liberty to design their own fully functional games from their original concept to a playable finished product, i.e., from the initial idea through to the wrapped box. The student teams will experience the entire game development cycle as they execute their projects. Responsibilities include creating a game idea, writing a story, developing the artwork, designing characters, implementing music and sound effects, programming and testing the game, and documenting the entire project. Recommended preparation: Junior or Senior standing and consent of instructor.

EECS 391. Introduction to Artificial Intelligence. 3 Units.

This course is an introduction to artificial intelligence. We will study the concepts that underlie intelligent systems. Topics covered include problem solving with search, constraint satisfaction, adversarial games, knowledge representation and reasoning using propositional and first order logic, reasoning under uncertainty, introduction to machine learning, automated planning, reinforcement learning and natural language processing. Recommended: basic knowledge of probability and statistics. Prereq: ENGR 131 or EECS 132.

EECS 393. Software Engineering. 3 Units.

Topics: Introduction to software engineering; software lifecycle models; development team organization and project management; requirements analysis and specification techniques; software design techniques; programming practices; software validation techniques; software maintenance practices; software engineering ethics. Undergraduates work in teams to complete a significant software development project. Graduate students are required to complete a research project. Recommended preparation for EECS 493: EECS 337. Offered as EECS 393 and EECS 493. Counts as SAGES Senior Capstone. Prereq: EECS 337.

EECS 394. Introduction to Information Theory. 3 Units.

This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended Preparation: MATH 201 or MATH 307. Offered as MATH 394, EECS 394, MATH 494 and EECS 494. Prereq: MATH 223 and MATH 380 or requisites not met permission.

EECS 395. Senior Project in Computer Science. 4 Units.

Capstone course for computer science seniors. Material from previous and concurrent courses used to solve computer programming problems and to develop software systems. Professional engineering topics such as project management, engineering design, communications, and professional ethics. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Scheduled formal project presentations during last week of classes. Counts as SAGES Senior Capstone. Prereq: Senior standing.

EECS 396. Independent Projects. 1 - 6 Unit.

Independent projects in Computer Engineering, Computer Science, Electrical Engineering, and Systems and Control Engineering. Limited to juniors and seniors. Prereq: Limited to juniors and seniors.

EECS 397. Special Topics. 1 - 6 Unit.

Special topics in Computer Engineering, Computer Science, Electrical Engineering, and Systems and Control Engineering. Prereq: Limited to juniors and seniors.

EECS 398. Engineering Projects I. 4 Units.

Capstone course for electrical, computer and systems and control engineering seniors. Material from previous and concurrent courses used to solve engineering design problems. Professional engineering topics such as project management, engineering design, communications, and professional ethics. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Scheduled formal project presentations during last week of classes. Counts as SAGES Senior Capstone. Prereq: Senior Standing. Prereq or Coreq: ENGR 398 and ENGL 398.

EECS 399. Engineering Projects II. 3 Units.

Continuation of EECS 398. Material from previous and concurrent courses applied to engineering design and research. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Prereq: Senior Standing.

EECS 400T. Graduate Teaching I. 0 Units.

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. Recommended preparation: Ph.D. student in EECS department.

EECS 401. Digital Signal Processing. 3 Units.

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. Recommended preparation: EECS 313.

EECS 405. Data Structures and File Management. 3 Units.

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. Recommended preparation: EECS 233 and MATH 304.

EECS 408. Introduction to Linear Systems. 3 Units.

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. Recommended preparation: EECS 304.

EECS 409. Discrete Event Systems. 3 Units.

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 412. Electromagnetic Fields III. 3 Units.

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 Units.

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. Recommended preparation: Concurrent enrollment in EECS 408.

EECS 415. Integrated Circuit Technology I. 3 Units.

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. Recommended preparation: EECS 322.

EECS 416. Convex Optimization for Engineering. 3 Units.

This course will focus on the development of a working knowledge and skills to recognize, formulate, and solve convex optimization problems that are so prevalent in engineering. Applications in control systems; parameter and state estimation; signal processing; communications and networks; circuit design; data modeling and analysis; data mining including clustering and classification; and combinatorial and global optimization will be highlighted. New reliable and efficient methods, particular those based on interior-point methods and other special methods to solve convex optimization problems will be emphasized. Implementation issues will also be underscored. Recommended preparation: MATH 201 or equivalent.

EECS 417. Introduction to Stochastic Control. 3 Units.

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. Recommended preparation: EECS 408.

EECS 418. System Identification and Adaptive Control. 3 Units.

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 Units.

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.

EECS 421. Optimization of Dynamic Systems. 3 Units.

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. Recommended preparation: EECS 408. Offered as EECS 421 and MATH 434.

EECS 422. Solid State Electronics II. 3 Units.

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 Units.

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. Recommended preparation: EECS 338.

EECS 424. Introduction to Nanotechnology. 3 Units.

An exploration of emerging nanotechnology research. Lectures and class discussion on 1) nanostructures: superlattices, nanowires, nanotubes, quantum dots, nanoparticles, nanocomposites, proteins, bacteria, DNA; 2) nanoscale physical phenomena: mechanical, electrical, chemical, thermal, biological, optical, magnetic; 3) nanofabrication: bottom up and top down methods; 4) characterization: microscopy, property measurement techniques; 5) devices/applications: electronics, sensors, actuators, biomedical, energy conversion. Topics will cover interdisciplinary aspects of the field. Offered as EECS 424 and EMAE 424.

EECS 425. Computer Networks I. 3 Units.

An introduction to computer networks and the Internet. Applications: http, ftp, e-mail, DNS, socket programming. Transport: UDP, TCP, reliable data transfer, and congestion control. Network layer: IP, routing and NAT. Link layer: taxonomy, Ethernet, 802.11. Recommended preparation: EECS 338 or consent of instructor.

EECS 426. MOS Integrated Circuit Design. 3 Units.

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. Recommended preparation: EECS 344 and EECS 321.

EECS 427. Optoelectronic and Photonic Devices. 3 Units.

In this course, we will study the optical transitions, absorptions, and gains in semiconductors. We will discuss the optical processes in semiconductor bulk as well as low dimensional structures such as quantum well and quantum dot. The fundamentals, technologies and applications of important optoelectronic devices (e.g., light-emitting diodes, semiconductor lasers, solar cells and photo-detectors) will be introduced. We will learn the current state-of-the-art of these devices. Recommended Preparation: EECS 321.

EECS 428. Computer Communications Networks II. 3 Units.

Introduction to topics and methodology in computer networks and middleware research. Traffic characterization, stochastic models, and self-similarity. Congestion control (Tahoe, Reno, Sack). Active Queue Management (RED, FQ) and explicit QoS. The Web: overview and components, HTTP, its interaction with TCP, caching. Overlay networks and CDN. Expected work includes a course-long project on network simulation, a final project, a paper presentation, midterm, and final test. Recommended preparation: EECS 425 or permission of instructor.

EECS 433. Database Systems. 3 Units.

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. Recommended preparation: EECS 341 and MATH 304.

EECS 434. Microfabricated Silicon Electromechanical Systems. 3 Units.

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. Recommended preparation: EECS 322 or EECS 415.

EECS 435. Data Mining. 3 Units.

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. Recommended preparation: EECS 341 or equivalent.

EECS 437. Advanced Topics in Data Mining and Bioinformatics. 3 Units.

This course will cover a large number of active data mining and bioinformatics research areas, which include but not limited to: text mining, sequence analysis, network/graph mining, microarray analysis, and mining mobile objects. Students are expected to understand various methods and approaches employed in these research areas and have critical thinking on the advantages and disadvantages of these approaches. In addition, students need to complete a course-long project which exhibits the independent research capability in these data mining and bioinformatics areas. Recommended preparation: EECS 340, EECS 435.

EECS 439. Web Data Mining. 3 Units.

Web crawling technology, web search and information extraction, unsupervised and semi-supervised learning techniques and their application to web data extraction, social network analysis, various pagerank algorithms, link analysis, web resource discovery, web, resource description framework (RDF), XML, Web Ontology Language (OWL). Recommended preparation: EECS 338, EECS 341.

EECS 440. Machine Learning. 3 Units.

Machine learning is a subfield of Artificial Intelligence that is concerned with the design and analysis of algorithms that "learn" and improve with experience. While the broad aim behind research in this area is to build systems that can simulate or even improve on certain aspects of human intelligence, algorithms developed in this area have become very useful in analyzing and predicting the behavior of complex systems. Machine learning algorithms have been used to guide diagnostic systems in medicine, recommend interesting products to customers in e-commerce, play games at human championship levels, and solve many other very complex problems. This course is focused on algorithms for machine learning: their design, analysis and implementation. We will study different learning settings, including supervised, semi-supervised and unsupervised learning. We will study different ways of representing the learning problem, using propositional, multiple-instance and relational representations. We will study the different algorithms that have been developed for these settings, such as decision trees, neural networks, support vector machines, k-means, harmonic functions and Bayesian methods. We will learn about the theoretical tradeoffs in the design of these algorithms, and how to evaluate their behavior in practice. At the end of the course, you should be able to: --Recognize situations where machine learning algorithms are applicable; --Understand, represent and formulate the learning problem; --Apply the appropriate algorithm(s), or if necessary, design your own, with an understanding of the tradeoffs involved; --Correctly evaluate the behavior of the algorithm when solving the problem. Prereq: EECS 391 or EECS 491 or consent of instructor.

EECS 441. Internet Applications. 3 Units.

This course exposes students to research in building and scaling internet applications. Covered topics include Web services, scalable content delivery, applications of peer-to-peer networks, and performance analysis and measurements of internet application platforms. The course is based on a collection of research papers and protocol specifications. Students are required to read the materials, present a paper in class, prepare short summaries of discussed papers, and do a course project (team projects are encouraged). Prereq: EECS 325 or EECS 425.

EECS 444. Computer Security. 3 Units.

General types of security attacks; approaches to prevention; secret key and public key cryptography; message authentication and hash functions; digital signatures and authentication protocols; information gathering; password cracking; spoofing; session hijacking; denial of service attacks; buffer overruns; viruses, worms, etc., principles of secure software design, threat modeling; access control; least privilege; storing secrets; socket security; RPC security; security testing; secure software installation; operating system security; database security; web security; email security; firewalls; intrusions. Recommended preparation: EECS 337.

EECS 450. Operations and Systems Design. 3 Units.

Introduction to design, modeling, and optimization of operations and scheduling systems with applications to computer science and engineering problems. Topics include, forecasting and times series, strategic, tactical, and operational planning, life cycle analysis, learning curves, resources allocation, materials requirement and capacity planning, sequencing, scheduling, inventory control, project management and planning. Tools for analysis include: multi-objective optimization, queuing models, simulation, and artificial intelligence.

EECS 451. Introduction to Digital Communications. 3 Units.

Analysis and design of modern digital communications systems: introduction to digital communication systems, review of basic analog and digital signal processing for both deterministic and stochastic signals, signal space representation, basis functions, projections and matched filters, pulse shaping, pulse amplitude modulation, quadrature amplitude modulation, deterministic performance and performance in noise, carrier frequency and phase tracking, symbol timing synchronization, source coding and channel coding. Extensive computer-based design exercises using Matlab and Simulink to design and test digital modems and communication systems. Prereq: STAT 332 or equivalent.

EECS 452. Random Signals. 3 Units.

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 Units.

This course covers fundamental topics in algorithm design and analysis in depth. Amortized analysis, NP-completeness and reductions, dynamic programming, advanced graph algorithms, string algorithms, geometric algorithms, local search heuristics. Offered as EECS 454 and OPRE 454. Prereq: EECS 340.

EECS 458. Introduction to Bioinformatics. 3 Units.

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. Recommended preparation: EECS 340, EECS 233.

EECS 459. Bioinformatics for Systems Biology. 3 Units.

Description of omic data (biological sequences, gene expression, protein-protein interactions, protein-DNA interactions, protein expression, metabolomics, biological ontologies), regulatory network inference, topology of regulatory networks, computational inference of protein-protein interactions, protein interaction databases, topology of protein interaction networks, module and protein complex discovery, network alignment and mining, computational models for network evolution, network-based functional inference, metabolic pathway databases, topology of metabolic pathways, flux models for analysis of metabolic networks, network integration, inference of domain-domain interactions, signaling pathway inference from protein interaction networks, network models and algorithms for disease gene identification, identification of dysregulated subnetworks network-based disease classification. Offered as EECS 459 and SYBB 459. Prereq: EECS 359 or EECS 458 or BIOL 250.

EECS 460. Manufacturing and Automated Systems. 3 Units.

Formulation, modeling, planning, and control of manufacturing and automated systems with applications to computer science and engineering problems. Topics include, design of products and processes, location/spatial problems, transportation and assignment, product and process layout, group technology and clustering, cellular and network flow layouts, computer control systems, reliability and maintenance, and statistical quality control. Tools and analysis include: multi-objective optimization, artificial intelligence, and heuristics for combinatorial problems. Offered as EECS 360 and EECS 460.

EECS 466. Computer Graphics. 3 Units.

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. Recommended preparation: EECS 233.

EECS 467. Commercialization and Intellectual Property Management. 4 Units.

This interdisciplinary course covers a variety of topics, including principles of intellectual property and intellectual property management, business strategies and modeling relevant to the creation of start-up companies and exploitation of IP rights as they relate to biomedical-related inventions. The goal of this course is to address issues relating to the commercialization of biomedical-related inventions by exposing law students, MBA students, and Ph.D. candidates (in genetics and proteomics) to the challenges and opportunities encountered when attempting to develop biomedical intellectual property from the point of early discovery to the clinic and market. Specifically, this course seeks to provide students with the ability to value a given technological advance or invention holistically, focusing on issues that extend beyond scientific efficacy and include patient and practitioner value propositions, legal and intellectual property protection, business modeling, potential market impacts, market competition, and ethical, social, and healthcare practitioner acceptance. During this course, law students, MBA students, and Ph.D. candidates in genomics and proteomics will work in teams of five (two law students, two MBA students and one Ph.D. candidate), focusing on issues of commercialization and IP management of biomedical-related inventions. The instructors will be drawn from the law school, business school, and technology-transfer office. Please visit the following website for more information: fusioninnovate.com. Offered as LAWS 5341, MGMT 467, GENE 367, GENE 467, EBME 467 and EECS 467.

EECS 468. Power System Analysis I. 3 Units.

This course introduces the steady-state modeling and analysis of electric power systems. The course discusses the modeling of essential power system network components such as transformers and transmission lines. The course also discusses important steady-state analysis of three-phase power system network, such as the power flow and economic operation studies. Through the use of PowerWorld Simulator education software, further understanding and knowledge can be gained on the operational characteristics of AC power systems. Special topics concerning new grid technologies will be discussed towards the semester end. The prerequisite requirements of the course include the concepts and computational techniques of Alternative Current (AC) circuit and electromagnetic field. Offered as EECS 368 and EECS 468. Prereq: EECS 245.

EECS 469. Power System Analysis II. 3 Units.

This course extends upon the steady state analysis of power systems to cover study topics that are essential for power system planning and operation. Special system operating conditions are considered, such as unbalanced network operation and component faults. Among the most important analytical methods developed, are symmetrical components and sequence networks. Other study topics discussed include the electric machine modeling and power system transient stability. The latter half of the course presents computational methods and control algorithms that are essential for power system operation, such as generation control and state estimation. Offered as EECS 369 and EECS 469. Prereq: EECS 368.

EECS 470. Smart Grid. 3 Units.

This course starts with an introduction to the US electric power system infrastructure and national electricity policy. Then power system operations and reliability practices are described. In the context of currently existing infrastructure and operation strategies, the course discusses the new Smart Grid technologies such as renewable resources, distributed generation, demand response, energy storage and electric vehicles. Additional important topics of discussion include Advanced Meter Infrastructure, microgrids, the IEEE 1547 Interconnection Standard, and other interoperability standards. The course captures the evolving progress made in Smart Grid technologies and the impacts on power system economics and reliability. Offered as EECS 370 and EECS 470. Prereq: EECS 368.

EECS 474. Advanced Control and Energy Systems. 3 Units.

This course introduces applied quantitative robust and nonlinear control engineering techniques to regulate automatically renewable energy systems in general and wind turbines in particular. The course also studies the fundamentals for dynamic multidisciplinary modeling and analysis of large multi-megawatt wind turbines (mechanics, aerodynamics, electrical systems, control concepts, etc.). The course combines lecture sessions and lab hours. The 400-level includes an experimental lab competition, where the object is to design, implement, and experimentally validate a control strategy to regulate a real system in the laboratory (helicopter control competition or similar); it will also include additional project design reports. Offered as EECS 374 and EECS 474. Prereq: EECS 304.

EECS 475. Applied Control. 3 Units.

This course provides a practical treatment of the study of control engineering systems. It emphasizes best practices in industry so that students learn what aspects of plant and control system design are critical. The course develops theory and practice for digital computer control systems; PID controller design (modes, forms and tuning methods); Control structure design (feed-forward, cascade control, predictive control, disturbance observers, multi-loop configurations, multivariable control); Actuators, sensors and common loops; Dynamic performance evaluation; and some advanced control techniques (quantitative robust control, gain-scheduling and adaptive control) to achieve a good performance over a range of operating conditions. Recommended preparation: EECS 374 or EECS 474. Offered as EECS 375 and EECS 475. Prereq: EECS 304 or Requisites Not Met permission.

EECS 476. Mobile Robotics. 3 Units.

Design of software systems for mobile robot control, including: motion control; sensory processing; localization and mapping; mobile-robot planning and navigation; and implementation of goal-directed behaviors. The course has a heavy lab component involving a sequence of design challenges and competitions performed in teams.

EECS 477. Advanced Algorithms. 3 Units.

Design and analysis of efficient algorithms, with emphasis on network flow, combinatorial optimization, and randomized algorithms. Linear programming: duality, complementary slackness, total unimodularity. Minimum cost flow: optimality conditions, algorithms, applications. Game theory: two-person zero-sum games, minimax theorems. Probabilistic analysis and randomized algorithms: examples and lower bounds. Approximation algorithms for NP-hard problems: examples, randomized rounding of linear programs. Prereq: EECS 302, EECS 340, MATH 201, MATH 380.

EECS 478. Computational Neuroscience. 3 Units.

Computer simulations and mathematical analysis 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 learning, models of brain systems, and their relationship to artificial and neural networks. Term project required. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Recommended preparation: MATH 223 and MATH 224 or BIOL 300 and BIOL 306. Offered as BIOL 378, COGS 378, MATH 378, BIOL 478, EBME 478, EECS 478, MATH 478 and NEUR 478.

EECS 480A. Introduction to Wireless Health. 3 Units.

Study of convergence of wireless communications, microsystems, information technology, persuasive psychology, and health care. Discussion of health care delivery system, medical decision-making, persuasive psychology, and wireless health value chain and business models. Understanding of health information technology, processing of monitoring data, wireless communication, biomedical sensing techniques, and health monitoring technical approaches and solutions. Offered as EECS 480A and EBME 480A.

EECS 480B. The Human Body. 3 Units.

Study of structural organization of the body. Introduction to anatomy, physiology, and pathology, covering the various systems of the body. Comparison of elegant and efficient operation of the body and the related consequences of when things go wrong, presented in the context of each system of the body. Introduction to medical diagnosis and terminology in the course of covering the foregoing. Offered as EECS 480B and EBME 480B.

EECS 480C. Biomedical Sensing Instrumentation. 3 Units.

Study of principles, applications, and design of biomedical instruments with special emphasis on transducers. Understanding of basic sensors, amplifiers, and signal processing. Discussion of the origin of biopotential, and biopotential electrodes and amplifiers (including biotelemetry). Understanding of chemical sensors and clinical laboratory instrumentation, including microfluidics. Offered as EECS 480C and EBME 480C. Prereq: EECS/EBME 480A, EECS/EBME 480B

EECS 480D. The Health Care Delivery Ecosystem. 3 Units.

Health care delivery across the continuum of care in the United States, including health policy and reform, financing of care, comparative health systems, population health, public health, access to care, care models, cost and value, comparative effectiveness, governance, management, accountability, workforce, and the future. Discussions of opportunities and challenges for wireless health, integrated into the foregoing topics. Perspective on health care delivery in other countries. Offered as EECS 480D and EBME 480D.

EECS 480E. Wireless Communications and Networking. 3 Units.

Essentials of wireless communications and networking, including teletraffic engineering, radio propagation, digital and cellular communications, wireless wide-area network architecture, speech and channel coding, modulation schemes, antennas, security, networking and transport layers, and 4G systems. Hands-on learning of the anatomy of a cell phone, and a paired wireless health device and its gateway. Offered as EECS 480E and EBME 480E.

EECS 480F. Physicians, Hospitals and Clinics. 3 Units.

Rotation through one or more health care provider facilities for a first-hand understanding of care delivery practice, coordination, and management issues. First-hand exposure to clinical personnel, patients, medical devices and instruments, and organizational workflow. Familiarity with provider protocols, physician referral practices, electronic records, clinical decision support systems, acute and chronic care, and inpatient and ambulatory care. Offered as EECS 480F and EBME 480F.

EECS 480G. Applied Cryptography. 3 Units.

This course begins with a discussion of how mobility-driven computing and communication systems use cryptography to protect data and protocols. The foundation for critical cryptographic concepts, techniques, and algorithms are covered. The fundamental cryptographic concepts are studied, including: symmetric encryption, public key encryption, digital signatures, cryptographic hash function, and message authentication codes; cryptographic protocols, such as key exchange, remote user authentication, and interactive proofs; cryptanalysis of cryptographic primitives and protocols, such as by side-channel attacks, differential cryptanalysis, or replay attacks; and cryptanalytic techniques on deployed systems, such as memory remanence, timing attacks, fault attacks, and differential power analysis. Techniques used for code making (cryptographic) and break codes (cryptanalytic) are covered, as well as how these techniques are used within larger security systems.

EECS 480H. Software Security. 3 Units.

This course begins with discussions of good software engineering practices to ensure security in modern software systems and additional challenges to security due to code mobility in software for mobility-driven computing. The basics of software security and threat models, methods to protect software (operating systems, databases, distributed software) - including risk analysis, authentication and authorization, access control, and software architecture for security - are studied. Principles of secure coding, validation and verification of secure software, software and data watermarking, code obfuscation, tamper resistant software are studied, as well as the benefits of open source and closed source software. Use of software as an attack mechanism and emerging attack models (including joint hardware-software attacks) are studied.

EECS 480K. Hardware Security. 3 Units.

This course begins with the keys to enabling secure, trustworthy operation of computer hardware - understanding security issues and how appropriate security measures are included during design, verification, test, and deployment. Increasingly the security primitives such as the Trusted Computing Module are being introduced at the hardware level to prevent the compromise of security in systems being deployed today. A comprehensive coverage of security issues in computer hardware is provided. Topics of embedded systems security, hardware Trojans, security in implantable medical devices, security in RFID/NFC, protection from side channel attacks, tamper resistance and crypto processor design, trusted FPGA design/JTAG, hardware-based cryptanalysis, and hardware IP protection against piracy and reverse-engineering are covered. A course project (Can you Hack It?) that challenges students to hack a hardware is included.

EECS 480M. Introduction to Medical Informatics. 3 Units.

Current state and emerging trends in Medical Informatics (MI) and associated health information systems. Principles, data, data management, system interoperability, patient privacy, information security, electronic records, telehealth, regulatory issues, clinical decision support, mobile documentation, devices and wireless communications in healthcare. Impact of wireless technology on emerging health information systems and processes. Offered as EECS 480M and EBME 480M.

EECS 480N. Introduction to Health Decision and Knowledge Support Systems. 3 Units.

Current state and emerging trends in use of decision support systems (DSS) and knowledge support systems (KSS) in health care delivery. Information, knowledge and decision principles; Health data; Clinical decision and knowledge support, DSS/KSS development and adoption, and regulatory issues. Impact of wireless technology on emerging DSS and KSS, and related processes. Offered as EBME 480N and EBME 480N

EECS 480O. Introduction to Health Information Technology Implementation. 3 Units.

Current state and emerging trends in the implementation and adoption of health information technology (HIT). Macroergonomics; Technology transfer and adoption; Systems adoption life cycle; Impact of regulation; Decision and work transformation; HIT specification and acquisition; Contracting issues; Implementation, use, and evaluation; Impact of wireless technology on emerging processes. Offered as EECS 480O and EBME 480O. Prereq: EECS 480M.

EECS 480P. Advanced Biomedical Instrumentation. 3 Units.

Analysis and design of biosensors in the context of biomedical measurements. Base sensors using electrochemical, optical, piezoelectric, and other principles. Binding equilibria, enzyme kinetics, and mass transport modalities. Adding the "bio" element to base sensors and mathematical aspects of data evaluation. Applications to clinical problems and biomedical research. Offered as EECS 480P and EBME 480P.

EECS 480Q. Regulatory Policy and Regulations. 3 Units.

Introduction of wireless health technologies: spectrum, licensed versus unlicensed; personal area networks; body area networks; ultra-wideband low energy level short-range radios; wireless local area networks; wide area networks. The Federal system: separation of powers; the executive branch and its departments; the House of Representatives and its committees; the Senate and its committees; the FCC; policy versus regulatory versus legislative. What is a medical device: FDA; classification system; radiation-emitting products; software; RF in medical devices; converged medical devices; international aspects. Regulation of health information technology and wireless health: American Recovery and Reinvestment Act; Patient Protection and Affordable Care Act; FCC/ FDA MoU; CMS and Reimbursement; privacy and security. Offered as EECS 480Q and EBME 480Q.

EECS 480R. User Experience Engineering. 3 Units.

Social, cognitive, behavioral, and contextual elements in the design of healthcare technology and systems. User-centered design paradigm from a broad perspective, exploring dimensions of product user experience and learning to assess and modify the design of healthcare technology. Practical utilization of user centered design method and assessment techniques for approaching a design problem. Offered as EECS 480R and EBME 480R.

EECS 480S. Wireless Health Product Development. 3 Units.

Integrating application requirements, market data, concept formulation, design innovation, and manufacturing resources for creating differentiated wireless health products that delight the user. Learning user-centric product development best practices, safety, security and privacy considerations, and risk management planning. Understanding the regulatory process. Identifying and managing product development tradeoffs. Offered as EECS 480S and EBME 480S. Prereq: EECS 480R.

EECS 480T. Wearable Computing Design. 3 Units.

Learning about wearable devices using flexible/conformal electronics designed for convenience and uninterrupted wear-ability. Examining related design challenges from the technology, human and business points of view. Understanding wearable product design for general and special-purpose tasks in information processing, media operations, and information extraction from sensed data. Learning about the technological challenges for design, including miniaturization, power delivery and management, data storage, and wireless networking. Learning about hardware choices (processor, field programmable gate array or custom ASIC based design) for wearable computers and software architectures for smart data processing. Learning about wearable designs centered on the human experience, including sensing and interfacing with the human body, as well as user interaction, convenience, and support for non-intrusive social appearance. Case studies tying the business requirements with the technology and design issues.

EECS 480U. Wearable Computing Technology. 3 Units.

Learning about a broad range of cutting-edge technologies suitable for wearable computing. Understanding printed and flexible electronics technologies required for creating wearable computing, in particular organics for active components due to their flexibility or conformity. Examine the tradeoffs between flexible/conformal versus rigid electronics in the context of wearable computing. Reviewing the history of printed electronics used as conductors for membrane keypads, car windscreen heaters and RFID tag antennas-to name a few application examples. Reviewing the latest technology advances in functional components such as displays, lighting, transistors (p-type & n-type), memory, batteries, photovoltaics (PV), sensors, and conductors as well as integration/packaging steps. Understanding the market potential of these technologies by reviewing emerging products.

EECS 480W. Wearable Computing Manufacturing. 3 Units.

Learning about the supply chain and manufacturing processes for flexible electronics, sensors, and other technologies contributing to the development of wearable products. Understanding supply chain issues in low mobility materials, multilevel substrates, nanocomposites, materials for low power sensors, and inks suitable for direct printing. Identifying the tradeoffs involved in various manufacturing methods such as roll-to-roll manufacturing a mature coating technology yet to be proven for full device integration. Studying other manufacturing techniques such as plate-to-plate, direct printing, 3D printing, and screening techniques for their applicability to the manufacturing and integration of flexible electronics. Understanding the use of lithography and vapor deposition techniques in the context of flexible electronics. Examining the issues of systems integration and packaging of the manufactured products.

EECS 480X. Mobility-Driven Computing. 3 Units.

Fundamental concepts in computing and architecture for mobile devices, mobile operating systems, mobility and mobile data management. Application of technologies for location awareness, context awareness, integrated sensors, mobile Internet, displays, pattern recognition and natural language processing, and touch/gesture based user interaction. Understanding of the tradeoffs in design (smartphones, tablets) due to resource constraints such as wireless connectivity, application processing, power management, and graphics. Integration of near- and wide-area wireless communication technologies (Bluetooth, Wireless WAN). Exploration of emerging technologies and services for the mobile platform. Integration of the foregoing concepts in a specific mobile context application (home/office, pedestrian, vehicular).

EECS 480Y. Mobility-Driven Embedded Systems. 3 Units.

Foundations of reliable, energy-efficient and secure design of embedded systems. Fundamentals of mobility in embedded systems including wireless technology, location awareness, sensors, and actuators. Design consideration for processors, DSP, memory, and interfaces under mobility constraints (connectivity, power, and data management). Systems software for embedded computing, device management, and real-time I/O. Software design under constraints of size, performance, availability, and reliability. Software development techniques and practices (compilers, OS, and runtime systems). Case studies of mobility driven real-time embedded systems and software. Applications of mobility driven embedded systems, for example in biomedical implant systems.

EECS 480Z. Mobile Applications Development. 3 Units.

Understanding of the mobile application architecture, operating systems, and platforms. Challenges and opportunities in mobile application development. Evaluation of the leading mobile platform frameworks with respect to their features, functions, libraries, support, and ease of development. Software design for mobile applications in gaming, multimedia, entertainment, and enterprise applications. Development of enhanced user experience in a multi-touch, multi-sensor (accelerometer, gyroscopes, camera, geo-location) environment. Understanding of software development environments and testing tools, and use of wireless connectivity and data in mobile applications. Development of or extension of a modest application based on a major mobile platforms (iOS, Windows Phone 7, or Android).

EECS 483. Data Acquisition and Control. 3 Units.

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 Units.

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 Units.

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 Units.

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 488. Embedded Systems Design. 3 Units.

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 Units.

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. Recommended preparation: EMAE 181. Offered as EECS 489 and EMAE 489.

EECS 490. Digital Image Processing. 3 Units.

Digital images are introduced as two-dimensional sampled arrays of data. The course begins with one-to-one operations such as image addition and subtraction and image descriptors such as the histogram. Basic filters such as the gradient and Laplacian in the spatial domain are used to enhance images. The 2-D Fourier transform is introduced and frequency domain operations such as high and low-pass filtering are developed. It is shown how filtering techniques can be used to remove noise and other image degradation. The different methods of representing color images are described and fundamental concepts of color image transformations and color image processing are developed. One or more advanced topics such as wavelets, image compression, and pattern recognition will be covered as time permits. Programming assignments using software such as MATLAB will illustrate the application and implementation of digital image processing.

EECS 491. Artificial Intelligence: Probabilistic Graphical Models. 3 Units.

This course is a graduate-level introduction to Artificial Intelligence (AI), the discipline of designing intelligent systems, and focuses on probabilistic graphical models. These models can be applied to a wide variety of settings from data analysis to machine learning to robotics. The models allow intelligent systems to represent uncertainties in an environment or problem space in a compact way and reason intelligently in a way that makes optimal use of available information and time. The course covers directed and undirected probabilistic graphical models, latent variable models, associated exact and approximate inference algorithms, and learning in both discrete and continuous problem spaces. Practical applications are covered throughout the course. Prereq: EECS 391 or requisites not met permission.

EECS 492. VLSI Digital Signal Processing Systems. 3 Units.

Digital signal processing (DSP) can be found in numerous applications, such as wireless communications, audio/video compression, cable modems, multimedia, global positioning systems and biomedical signal processing. This course fills the gap between DSP algorithms and their efficient VLSI implementations. The design of a digital system is restricted by the requirements of applications, such as speed, area and power consumption. This course introduces methodologies and tools which can be used to design VLSI architectures with different speed-area tradeoffs for DSP algorithms. In addition, the design of efficient VLSI architectures for commonly used DSP blocks is presented in this class. Recommended preparation: EECS 485.

EECS 493. Software Engineering. 3 Units.

Topics: Introduction to software engineering; software lifecycle models; development team organization and project management; requirements analysis and specification techniques; software design techniques; programming practices; software validation techniques; software maintenance practices; software engineering ethics. Undergraduates work in teams to complete a significant software development project. Graduate students are required to complete a research project. Recommended preparation for EECS 493: EECS 337. Offered as EECS 393 and EECS 493. Counts as SAGES Senior Capstone.

EECS 494. Introduction to Information Theory. 3 Units.

This course is intended as an introduction to information and coding theory with emphasis on the mathematical aspects. It is suitable for advanced undergraduate and graduate students in mathematics, applied mathematics, statistics, physics, computer science and electrical engineering. Course content: Information measures-entropy, relative entropy, mutual information, and their properties. Typical sets and sequences, asymptotic equipartition property, data compression. Channel coding and capacity: channel coding theorem. Differential entropy, Gaussian channel, Shannon-Nyquist theorem. Information theory inequalities (400 level). Additional topics, which may include compressed sensing and elements of quantum information theory. Recommended Preparation: MATH 201 or MATH 307. Offered as MATH 394, EECS 394, MATH 494 and EECS 494.

EECS 495. Nanometer VLSI Design. 3 Units.

Semiconductor industry has evolved rapidly over the past four decades to meet the increasing demand on computing power by continuous miniaturization of devices. Now we are in the nanometer technology regime with the device dimensions scaled below 100nm. VLSI design using nanometer technologies involves some major challenges. This course will explain all the major challenges associated with nanoscale VLSI design such as dynamic and leakage power, parameter variations, reliability and robustness. The course will present modeling and analysis techniques for timing, power and noise in nanometer era. Finally, the course will cover the circuit/architecture level design solutions for low power, high-performance, testable and robust VLSI system. The techniques will be applicable to design of microprocessor, digital signal processor (DSP) as well as application specific integrated circuits (ASIC). The course includes a project which requires the student to work on a nanometer design issue. Recommended preparation: EECS 426 or EECS 485.

EECS 500. EECS Colloquium. 0 Units.

Seminars on current topics in Electrical Engineering and Computer Science.

EECS 500T. Graduate Teaching II. 0 Units.

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. Recommended preparation: Ph.D. student in EECS department.

EECS 516. Large Scale Optimization. 3 Units.

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. Recommended preparation: EECS 416.

EECS 518. Nonlinear Systems: Analysis and Control. 3 Units.

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. Recommended preparation: EECS 408.

EECS 520. Robust Control. 3 Units.

One of the most important problems in modern control theory is that of controlling the output of a system so as to achieve asymptotic tracking of prescribed signals and/or asymptotic rejection of undesired disturbances. The problem can be solved by the so-called regulator theory and H-infinity control theory. This course presents a self-contained introduction to these two important design methods. The intention of this course is to present ideas and methods on such a level that the beginning graduate student will be able to follow current research. Both linear and nonlinear results will be covered. Recommended preparation: EECS 408.

EECS 523. Advanced Neural Microsystems. 3 Units.

This course will cover the latest advances in neuroengineering with specific attention to integrated microsystems targeting wired/wireless multichannel interfacing with the nervous system at the cellular level in biological hosts. The aim is to provide students familiar with microfabrication and integrated circuit design with an application-driven, system-level overview of sensors and microelectronics in microsystems format for neural engineering. Recommended preparation: EECS 426.

EECS 526. Integrated Mixed-Signal Systems. 3 Units.

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. Recommended preparation: EECS 426.

EECS 527. Advanced Sensors: Theory and Techniques. 3 Units.

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.

EECS 531. Computer Vision. 3 Units.

The goal of computer vision is to create visual systems that recognize objects and recover structures in complex 3D scenes. This course emphasizes both the science behind our understanding of the fundamental problems in vision and the engineering that develops mathematical models and inference algorithms to solve these problems. Specific topics include feature detection, matching, and classification; visual representations and dimensionality reduction; motion detection and optical flow; image segmentation; depth perception, multi-view geometry, and 3D reconstruction; shape and surface perception; visual scene analysis and object recognition.

EECS 589. Robotics II. 3 Units.

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. Recommended preparation: EECS 489.

EECS 600. Special Topics. 1 - 18 Unit.

Offered as EECS 600 and SYBB 600.

EECS 600T. Graduate Teaching III. 0 Units.

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. Recommended preparation: Ph.D. student in EECS department.

EECS 601. Independent Study. 1 - 18 Unit.**EECS 602. Advanced Projects Laboratory. 1 - 18 Unit.****EECS 620. Special Topics. 1 - 18 Unit.****EECS 621. Special Projects. 1 - 18 Unit.****EECS 649. Project M.S.. 1 - 9 Unit.****EECS 651. Thesis M.S.. 1 - 18 Unit.****EECS 701. Dissertation Ph.D.. 1 - 18 Unit.**

Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Macromolecular Science and Engineering

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) are 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 BS, MS, or PhD degrees.

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, and in producing new materials which behave like classical polymers without being linked together by covalent bonds.

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 and mass spectroscopy, thermal and rheological analysis, determination of structure and morphology by x-ray diffraction, electron microscopy, and atomic force microscopy, permeability and free volume, 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. The integration of sensors and processing equipment, and methods for examining changes in structure and composition during processing steps are growing areas of inquiry. Both laboratory and simulation research are brought to bear on these critical issues.

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 photoluminescent and semi-conducting polymers for use in optoelectronic devices, polymers that are stable at high temperatures for fire-retardant construction materials, high temperature polymer electrolytes for use in advanced fuel cells, low density thermal insulating polymer composite materials, advanced polymeric optical devices, and biocompatible polymers for use in prosthetic implants, reconstructive medicine and drug-delivery vehicles.

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 applications in human health.

Undergraduate Programs

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 Bachelor of Science degree program in Polymer Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

The Case School of Engineering is proud that the polymer science and engineering program 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., biomaterials, chemical engineering, 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 BS 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 BS/MS 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.

Program Educational Objectives

This program will produce graduates who:

1. Are competent, creative, and highly valued professionals in industry, academia, or government.
2. Are flexible and adaptable in the workplace, possess the capacity to embrace new opportunities of emerging technologies, and embrace leadership and teamwork opportunities, all affording sustainable engineering careers.
3. Continue their professional development by obtaining advanced degrees in Polymer Science and Engineering or other professional fields, as well as medicine, law, management, finance or public policy.
4. Act with global, ethical, societal, ecological, and commercial awareness expected of practicing engineering professionals.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree in Polymer Science and Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs
- an ability to function in multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

Bachelor of Science in Engineering

Suggested Program of Study: Major in Polymer Science and Engineering

(standard track)

First Year	Units	
	Fall	Spring
Humanities/Social Science	3	
Principles of Chemistry for Engineers (CHEM 111)	4	
Elementary Computer Programming (ENGR 131) ^a	3	
Calculus for Science and Engineering I (MATH 121)	4	
FSCC 100 Sages First Seminar	4	
PHED Physical Education Activities		
SAGES University Seminar I ^b		3
Chemistry of Materials (ENGR 145) ^a		4

Calculus for Science and Engineering II (MATH 122)		4
General Physics I - Mechanics (PHYS 121)		4
PHED Physical Education Activities		
Year Total:	18	15

Second Year	Units	
	Fall	Spring
SAGES University Seminar II ^b	3	
Introductory Organic Chemistry I (CHEM 223)	3	
Introduction to Polymer Science and Engineering (EMAC 270)	3	
Calculus for Science and Engineering III (MATH 223)	3	
General Physics II - Electricity and Magnetism (PHYS 122)	4	
Humanities or Social Science		3
Introductory Organic Chemistry II (CHEM 224)		3
Polymer Properties and Design (EMAC 276) ((SAGES Departmental Seminar))		3
Statics and Strength of Materials (ENGR 200) ^a		3
Elementary Differential Equations (MATH 224)		3
Year Total:	16	15

Third Year	Units	
	Fall	Spring
Humanities or Social Sciences	3	
Natural Science elective ^c	3	
Chemical Laboratory Methods for Engineers (CHEM 290)	3	
Physical Chemistry for Engineering (EMAC 351)	3	
Technical elective I ^{d,e}	3	
Humanities or Social Sciences		3
Polymer Engineering (EMAC 376)		3
Polymer Analysis Laboratory (EMAC 355)		3
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)		3
Polymer Physics and Engineering (EMAC 352)		3
Technical elective II ^e		3
Year Total:	15	18

Fourth Year	Units	
	Fall	Spring
Introduction to Circuits and Instrumentation (ENGR 210) ^a	4	
Polymer Chemistry (EMAC 370)	3	
Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375)	3	
Polymer Processing (EMAC 377)	3	
Polymer Science and Engineering Project I (EMAC 398) ((SAGES Capstone Course)) ^f	3	
Open elective		3
Polymer Processing and Testing Laboratory (EMAC 372)		3
Polymer Engineer Design Product (EMAC 378)		3

Open elective	3	
Technical elective III ^e	3	
Year Total:	16	15
Total Units in Sequence:		128

Hours required for graduation: 129

- a Engineering Core Courses
- b Choice of USNA, USSO, or USSY course focused on thinking about the natural, social, or symbolic "world."
- c Approved Natural Science electives:
- PHYS 221 Introduction to Modern Physics
 - STAT 312 Basic Statistics for Engineering and Science
 - PHYS 349 Methods of Mathematical Physics I
 - BIOC 307 Introduction to Biochemistry: From Molecules To Medical Science
- d EMAC 325 may be taken as a technical elective. Students choosing the polymer major in the freshman year are encouraged to register for EMAC 125 (1 credit), which may be used as a technical elective provided the student also completes EMAC 325 for at least 2 credits.
- e Technical sequence must be approved by department advisor.
- f Preparation for the polymer science project should commence in the previous semester.

Bachelor of Science in Engineering**Suggested Program of Study: Major in Polymer Science and Engineering (biomaterials track)**

First Year	Units	
	Fall	Spring
Humanities or Social Sciences	3	
Principles of Chemistry for Engineers (CHEM 111)	4	
Elementary Computer Programming (ENGR 131) ^a	3	
Calculus for Science and Engineering I (MATH 121)	4	
FSCC 100 Sages First Seminar	4	
PHED Physical Education Activities		3
SAGES University Seminar I ^b		3
Chemistry of Materials (ENGR 145) ^a		4
Calculus for Science and Engineering II (MATH 122)		4
General Physics I - Mechanics (PHYS 121)		4
PHED Physical Education Activities		3
Year Total:	18	15

Second Year	Units	
	Fall	Spring
SAGES University Seminar II ^b	3	
Physiology-Biophysics I (EBME 201)	3	
Introduction to Polymer Science and Engineering (EMAC 270)	3	
Calculus for Science and Engineering III (MATH 223)	3	
General Physics II - Electricity and Magnetism (PHYS 122)	4	
Humanities or Social Sciences II		3

Physiology-Biophysics II (EBME 202) ^d	3	
Polymer Properties and Design (EMAC 276) (SAGES Departmental Seminar)	3	
Statics and Strength of Materials (ENGR 200) ^a	3	
Elementary Differential Equations (MATH 224)	3	
Year Total:	16	15

Third Year

	Units	
	Fall	Spring
Humanities or Social Sciences	3	
Introductory Organic Chemistry I (CHEM 223) ^d	3	
Chemical Laboratory Methods for Engineers (CHEM 290)	3	
Introduction to Biomedical Materials (EBME 306)	3	
Physical Chemistry for Engineering (EMAC 351)	3	
Technical Elective I ^e		3
Natural Science elective ^c		3
Introductory Organic Chemistry II (CHEM 224) ^d		3
Polymer Engineering (EMAC 376)		3
Structure of Biological Materials (EMAC 303)		3
Year Total:	15	15

Fourth Year

	Units	
	Fall	Spring
Humanities or Social Sciences	3	
Introduction to Circuits and Instrumentation (ENGR 210) ^a	4	
Polymer Chemistry (EMAC 370)	3	
Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375)	3	
Polymer Processing (EMAC 377)	3	
Technical elective II ^f	3	
Polymer Engineer Design Product (EMAC 378)		3
Polymer Science and Engineering Project I (EMAC 398) (SAGES Capstone Course) ^g		3
Professional Communication for Engineers (ENGL 398)		3
& Professional Communication for Engineers (ENGR 398)		3
Technical elective III ^f		3
Year Total:	19	12

Total Units in Sequence:**125****Hours required for graduation: 129**

- a Engineering Core Courses
- b Choice of USNA, USSO, or USSY course focused on thinking about the natural, social, or symbolic "world."
- c Approved Natural Science electives:
- BIOL 214 Genes, Evolution and Ecology (d);
 - BIOL 215 Cells and Proteins (d);
 - BIOC 307 Introduction to Biochemistry: From Molecules To Medical Science (d);
 - BIOL 362 Principles of Developmental Biology
- d Suggested for pre-med students

- e EMAC 355 Polymer Analysis Laboratory is strongly recommended.
- f At least 3 of the 4 Technical Electives have to be taken from:
- EBME 315 Applied Tissue Engineering;
 - EBME 316 Biomaterials for Drug Delivery;
 - EBME 325 Introduction to Tissue Engineering;
 - EBME 350 Quantitative Molecular, Cellular and Tissue Bioengineering;
 - EBME 408 Engineering Tissues/Materials - Learning from Nature's Paradigms;
 - EBME 426 Nanomedicine;
 - EMAC 471 Polymers in Medicine / EBME 406 Polymers in Medicine;
 - a three-credit research sequence of EMAC 125 Freshman Research on Polymers and EMAC 325 Undergraduate Research in Polymer Science
 - EMAC 372 Polymer Processing and Testing Laboratory (offered in the spring semester of the fourth year)
- g Preparation for the polymer science project should commence in the previous semester.

Minor in Polymer Science and Engineering

The minor in Polymer Science and Engineering consists of five courses from the list below (special arrangements can be made to include appropriate EMAC graduate courses as well).

Choose any five of the following: 15

EMAC 270	Introduction to Polymer Science and Engineering
EMAC 276	Polymer Properties and Design
EMAC 351	Physical Chemistry for Engineering
EMAC 355	Polymer Analysis Laboratory
EMAC 370	Polymer Chemistry
EMAC 372	Polymer Processing and Testing Laboratory
EMAC 375	Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology
EMAC 376	Polymer Engineering
EMAC 377	Polymer Processing
EMAC 378	Polymer Engineer Design Product

Total Units 15

Graduate Programs

Courses leading to the Master of Science (MS) and Doctor of Philosophy (PhD) 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 or her 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 MD/PhD 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.

Master of Science

Master's Thesis (Plan A)

The minimum requirement to complete a master's degree under Plan A is 27 hours. Of the 27 hours, at least 18 hours must be coursework, and 9 hours must be EMAC 651 Thesis M.S. (thesis research). At least 18 semester hours of coursework, including thesis, must be at the 400 level or higher.

All Plan A MS students must take 6 credits of departmental fundamentals courses including the lab component. Please note: Once a student begins registration of EMAC 651 Thesis M.S., the student must register for at least one credit hour of this course every semester until graduation. The normal residency period for an MS degree is 2 years.

For completion of master's degree Plan A, an oral examination (defense) of the master's thesis is required. The examination is conducted by a committee of three university faculty members. The candidate's thesis advisor usually serves as the chair of the examining committee. The chair of the department or the curricular program faculty appoints members of the committee. The examining committee must agree unanimously that the candidate has passed the thesis examination.

Master's Comprehensive (Plan B)

The master's Plan B program is available for individuals who live out-of-state or are working full-time. A research report and oral examination is required before graduation. This option requires 27 total credit hours; categorized by the following:

1. 3-6 cr. hrs. need to be project credit (independent study) which needs to be approved by advisor
2. 21-24 course credits (of which 9 must be based in Macromolecular Science); and
3. 6 core course credits.

Each candidate for the master's degree under Plan B must satisfactorily pass a comprehensive examination, which is administered by the department or curricular program committee. The examination may be written or oral or both. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required to register for one semester hour of EXAM 600 Master's Comprehensive Exam, before taking the examination.

Elective and core courses can be taken via Distance Learning (ITN) or by transfer (transfers need to be approved by chair of department and dean of graduate studies; core courses also needs instructors' approval).

Master of Science in Engineering with Specialization

Fire Science and Engineering

The Case School of Engineering at Case Western Reserve University offers an MS graduate program in Fire Science and Engineering. Students will choose either a Master of Science in Mechanical Engineering or a Master of Science in Macromolecular Science and Engineering, both with a concentration in fire science. Case Western

Reserve offers a unique intersection of expertise in macromolecular and combustion science and mechanical and chemical engineering, making us singularly suited to cover all aspects of fire protection, safety and flammability.

Through a 27-credit-hour curriculum, students explore and learn how to apply the fundamental principles of fire behavior and dynamics, protection and suppression systems, polymeric materials structure, properties and selection and more. The program is designed to be completed in a single 12 month year, but can be spread out over multiple years.

The Fire Science and Engineering program at Case Western Reserve covers all aspects of combustion and fire suppression. After graduating from this degree program, students will be ready to apply their thorough understanding of:

- The chemistry of fire and materials
- Flammability logistics
- Fire dynamics and fire behavior
- Fire risk assessment
- Fire protection engineering
- Combustion
- Fire and safety-related codes
- Human behavior and life safety analysis
- Structural fire protection
- Passive fire protection systems
- Polymer engineering

Elective tracks:

- Mechanical track to focus on mechanical engineering and combustion related to fire protection and suppression
- Materials track to focus on polymer chemistry and materials, and the chemistry of flammability and fire suppression

Degree Options

The Fire Science and Engineering master's degree program comprises 27 credit hours of classwork (9 courses) and a research paper. Students can choose to receive a Master of Science in Mechanical Engineering with a concentration in Fire Science and Engineering or a Master of Science in Macromolecular Science and Engineering with a concentration in Fire Science and Engineering.

All students will take six core Fire Science and Engineering courses as well as three courses within their chosen elective track of mechanical engineering or macromolecular science and engineering. The mechanical track follows a traditional mechanical engineering/combustion approach to fire protection and suppression, but with specialization classes in polymers. The materials track focuses on polymer chemistry and materials, and the chemistry of flammability and fire suppression.

For additional information, please contact:

David Schiraldi, Chair of the Department of Macromolecular Science and Engineering

James S. Tien, Leonard Case Jr. Professor of Engineering in Mechanical and Aerospace Engineering

How to Apply

Application to the Fire Science and Engineering program is handled through the university's School of Graduate Studies. Students will need to

know whether they wish to apply for the MS in Mechanical Engineering or the MS in Macromolecular Science and Engineering.

Students interested in applying to the Fire Science and Engineering program should already have a bachelor's degree in Chemistry, Chemical Engineering, Mechanical Engineering or Materials Science & Engineering and have taken the GRE. Additional application requirements include a statement of objectives, academic transcripts, and three letters of recommendation. International students will also need to take the Test of English as a Foreign Language (TOEFL). Read more about the university's full application procedure requirements here (<http://gradstudies.case.edu/prospect/admissions/apply.html>).

When you are ready to apply, electronic applications can be submitted here (<https://app.applyyourself.com/AYApplicantLogin/ApplicantConnectLogin.asp?id=casegrad>).

PhD Programs

The PhD program consists of 36 hours of coursework, including the departmental core courses and 18 credit hours of PhD thesis (EMAC 701 Dissertation Ph.D.) are required for the PhD degree, in addition to passing the research qualifying exam (oral proposal) and the written qualifying exam.

Of the coursework credit requirements, the core courses are designated as "depth" courses (12 credits). In addition, all students will take a minimum of two breadth courses in basic science and/or other departments in the School of Engineering (for a total of six credits). The remaining breadth requirements (up to 18 credits) are satisfied by course modules taken in Macromolecular Science and Engineering.

Each doctoral student is responsible for becoming sufficiently familiar with the research interests of the department or program faculty to choose in a timely manner a faculty member who will serve as the student's research advisor. The research advisor is expected to provide mentorship in research conception, methods, performance and ethics, as well as focus on development of the student's professional communication skills, building professional contacts in the field, and fostering the professional behavior standard of the field and research in general.

The research advisor also assists with the selection of three other faculty to serve as the required additional members of the dissertation advisory committee. This committee must be formed within the second semester following admission. Throughout the development and completion of the dissertation, these members are expected to provide constructive criticism and helpful ideas generated by the research problem from the viewpoint of their particular expertise. Each member will make an assessment of the originality of the dissertation, its value, the contribution it makes and the clarity with which concepts are communicated, especially to a person outside the field.

The doctoral student is expected to arrange meetings and maintain periodic contact with each committee member. A meeting of the full committee for the purpose of assessing the student's progress should occur at least once a year until the completion of the dissertation.

For students entering the PhD program with a MS degree, 18, instead of 36 credit hours, of coursework is required. Other requirements for a PhD remain the same as described above. Normally students should orient their training around their main area of interest/expertise and in relation to their research program. For those enrolled in the MD/PhD degree

program, all 18 course credits for breadth and depth courses must be taken within the Medical School Program.

The core courses designated as depth courses are:

EMAC 401	Polymer Foundation Course I: Organic Chemistry	3
EMAC 402	Polymer Foundation Course II: Physical Chemistry	3
EMAC 403	Polymer Foundation Course III: Physics	3
EMAC 404	Polymer Foundation Course IV: Engineering	3

Students are required to take all four depth courses (12 credits), but on the approval of the instructor, can be excused from one or more of the courses if the relevant course content is not satisfied by a course taken in prior undergraduate or graduate degrees. However, the excused credits must be fulfilled by taking additional breadth courses. NOTE: While EMAC 401 Polymer Foundation Course I: Organic Chemistry and EMAC 402 Polymer Foundation Course II: Physical Chemistry, and and EMAC 404 Polymer Foundation Course IV: Engineering are offered at the same time in the Fall and Spring semesters, respectively, students can still sign up for both courses, since one is offered in the first half and the other in the second half of the semester.

Two courses in basic science and/or engineering are required. These courses can be taken in other departments of the School of Engineering, or in the departments of Mathematics, Biology, Biochemistry, Chemistry, or Physics as approved by the advisor.

As part of the course requirements, all students are required to register for EMAC 677 Colloquium in Macromolecular Science and Engineering (the Friday departmental seminars) which will be graded with either "Pass" or "No Pass."

Students who have taken EMAC 370 Polymer Chemistry and EMAC 376 Polymer Engineering as undergraduates can use these courses to fulfill one or more of the depth requirements in the Department of Macromolecular Science and Engineering for the MS and PhD degree. However, the credits for this course cannot be applied towards the course credit requirements for the graduate degree. Exceptions are possible for the combined BS/MS program.

Engineering School Requirements

Depth: The foundation courses are deemed to satisfy the depth requirements (12 credits).

Breadth: Two courses in basic science and/or other departments in the School of Engineering (for a total of six credits). The remaining breadth requirements (18 credits) are satisfied by course modules taken in Macromolecular Science and Engineering.

Graduate Rules

Graduates entering the Department of Macromolecular Science and Engineering are subject to the academic rules of the University, of the School of Engineering, and of the Department. Consult the Graduate Student Handbook (<http://gradstudies.case.edu>).

A short abstract of important points include:

1. GPA requirements are described below in the Departmental Rules.
2. A student receiving a "U" in a course is automatically placed on probation and must remove him/herself from probation within one year (usually by repeating the course). If a course is repeated, both original and revised grades will count in the grade point average.

3. Some students are admitted on a probationary basis and must achieve a 3.0 GPA after two semesters to remain in good standing (this is a rule of the Engineering School).
4. Students entering the graduate program for a PhD will need to fill out the "Planned Program of Study" **by the end of their second semester.**
5. All students are required to serve as teaching assistants. Responsibilities as a TA include serving as an instructor, lab assistant, recitation leader, grader, or tutor in an undergraduate course. After fulfilling the required teaching assistant program, UNIV 400, students will **make sure that three teaching courses (400T, 500T, and 600T) are listed on their Planned Program of Study.** Completion of this teaching requirement will be monitored by Graduate Studies and is required in order to graduate.

Engineering School Rules

Most of these rules are incorporated in the number and type of courses required by the Department. However, Case School of Engineering PhD students are required to 1) maintain full-time status as a PhD bound student; 2) maintain a grade point average of 3.2 or above; and 3) continue making satisfactory academic progress as certified by their advisor.

Departmental Rules

1. Students in the PhD program receiving a GPA below 2.50 in any two consecutive semesters will be asked to terminate their graduate study program.
2. The GPA requirement established by the university at various stages of the graduate program shall exclude MS or PhD thesis credits which will be graded "S" or "U" until a final grade is given at the end of the program. Hence a student must maintain a minimum GPA of 2.75 (for an MS) OR a 3.0 (for a PhD) in coursework. (As mentioned above, Case School of Engineering PhD students must maintain a GPA of 3.2 or above.)
3. Plan A MS students must give a departmental seminar (as part of the student lecture series).
4. Plan B MS degrees are limited to non-fellowship students.
5. Coursework may be transferred from another university, subject to Graduate Committee approval if:
 - the courses duplicate requirements of the department;
 - the courses were in excess of the undergraduate degree requirements; or
 - the courses were taken in a graduate program elsewhere;
 - a grade of B or better was achieved in those courses;
 - a petition is made to and approved by the Graduate Committee of the Department
 - the transferred grades will not count in the GPA at CWRU
6. The Department reserves the right to withhold financial support to a student if that student takes an undue amount of time in completing his/her MS or PhD requirements (normally no longer than 3 years for MS and 5 years after initial registration of EMAC 701 Dissertation Ph.D..
7. A PhD student must pass the written Qualifying Exam within 18 months after enrollment with a MS degree into the PhD program. A PhD student must pass the written Qualifying Exam within 24 months after enrollment with a BS degree into the PhD program. A student only has two chances to pass the Qualifying Exam.

Students will be asked to answer 4 mandatory questions – one from each of the following five areas:

- Polymer Synthesis
- Polymer Physical Chemistry
- Polymer Physics
- Applied Polymer Science
- Seminars (from the previous year)

Two elective questions will be chosen from a number of questions from all elective courses offered in the Department. NOTE: The Qualifying Exam is given twice per year respectively on the first Friday in the beginning and the first Friday after the end of the Spring semester. For PhD students enrolled in a Spring semester, those with MS must pass the Qualifying Exam at the end of his/her second Spring semester, and those with BS must pass it at the beginning of his/her third Spring semester.

8. The Research Qualifying Exam (RQE) is designed to test the student's knowledge of the chosen field as well as his/her originality and ability to perform high quality, independent research. It consists of a written research proposal and an oral defense. All PhD students who hold an MS degree must pass the RQE within 2 years of enrolling in the PhD program, while students with a BS degree must do so within 2.5 years. Successful passing of the Written Qualifying Exam (not to be confused with the written portion of this RQE) is prerequisite to taking the RQE. Students have two chances to pass the RQE and no student will be allowed to continue on to a PhD degree if he/she has not successfully taken it. A conditional pass with major revision (see below) requires modification to the written or oral portion, at the examination committee discretion, within ten business days and following guidelines by the examination committee. A second exam, if required due to failure of the first exam, must be taken within six months of the first exam with at least one examination committee member remaining the same. Passing the exam constitutes advancement to candidacy and is required for enrolling in EMAC 701 Dissertation Ph.D..
9. At least three (3) weeks prior to the RQE oral defense, the student will submit to the graduate chairperson a research proposal title with a one-paragraph synopsis of the research problem and approach, along with suggestions for two members ((i) and (ii), below) of the three member examining committee. The examining committee will consist of three faculty members: (i) a member (or intended member) of the student's Thesis Advisory Committee, (ii) an expert in the research proposal area and (iii) a faculty member selected systematically and in a neutral manner by the Graduate Committee. The student's primary thesis advisor or co-advisors is/are excluded from the examining committee. Upon establishing the examining committee, the student will arrange with the committee for the date, time, and location of the RQE. The student will then distribute the written research proposal to the examining committee five full business days before the defense. It should be no less than 15 and no more than 20 pages of double-spaced text with 1" margins on all sides. No more than 5 pages can be devoted to the proposal introduction or background. Figures, tables, and schemes should not exceed five pages in total. Literature citations are in addition to this page count. The oral presentation will be chaired by a designated chairperson from the examining committee. It should contain only limited background material, focusing primarily on execution of the proposed research. The oral presentation should last 20-30 minutes, with questions from faculty being for clarification only. Following the presentation, the examining committee will ask questions for

the student to answer concerning the proposal. On the basis of the written proposal and oral defense (presentation and question responses) the faculty will then confer and tender a decision of pass, conditional pass with major revision, or fail, immediately. The decision will be communicated to the student and graduate chairperson in writing within one business day.

10. All PhD students are required to fulfill their teaching requirement by registering for the three teaching courses, 400T, 500T, and 600T that will be posted to the departmental roster each semester. Completion of the teaching requirement will be monitored by Graduate Studies, and these three teaching courses **must appear both on the Program of Study form and the student's transcript.**
11. It is expected that all students will present the results of their research in a Departmental Seminar. This is mandatory for students enrolled in the PhD program. Attendance and registration for these seminars EMAC 677 Colloquium in Macromolecular Science and Engineering: Colloquia Seminars is also mandatory.
12. The department requires the equivalent of six credit hours of departmental assistance. This requirement takes the form of grading, laboratory assistance and/or general departmental duties and is designed to utilize no more than three hours/week of a student's time. The departmental service requirement must be completed within the first two semesters of study. However, the departmental service requirement form **must be turned in at the end of the each semester until the obligation is met.**
13. Vacation Policy. Graduate students in the department who receive fellowship support for 12 months are normally entitled to two weeks vacation plus national holidays. Alternative arrangements may be made with the student's advisor, giving ample advance notice. In certain situations it is possible to take a leave of absence without financial support.
14. Prior to graduation a student is required to clean out his/her laboratory space including a removal of waste solvents and hazardous material.
15. Failure to comply with all of the above course requirements may result in termination or delay graduation.

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 NMR, MALDI-TOF, and TA-Instruments Thermal Characterization instrumentation are located in the basement. Modern, computer-interfaced classrooms are installed on the ground floor. Additional instrumentation available includes Small and Wide-Angle X-ray diffractometers; scanning electron microscopy; a complete range of molecular spectroscopic equipment including FTIR, laser Raman, and high resolution solution and solid-state NMR (including imaging), as well as Raman and FTIR microscopes; and dynamic light scattering spectroscopy. There are also facilities for polymer characterization (molecular weight distribution), optical microscopy, solution and bulk rheology, scanning calorimetry, and for

testing and evaluating the mechanical properties of materials. A newly built-out processing lab provides the complete suite of Thermo-Fisher batch, single- and twin-screw mixing and extrusion equipment, as well as that manufacturer's state of the art rheometers. The C. Richard Newpher polymer processing laboratory includes a high temperature Rheometrics RMS-800 dynamic mechanical spectrometer, a Bomem DA-3 FTIR with FT-Raman capabilities, 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. Additional mechanical testing of fibers, films and injection-molded (Boy model 22-S) are provided by MTS universal testers which are used for both research and undergraduate teaching laboratory classes. The NSF Center for Layered Polymeric Systems (CLiPS) has its central facility within the department, with three cutting-edge multilayer extrusion systems as its centerpiece. CLiPS also operates a Bruckner KARO IV biaxial stretching unit, which allows controlled biaxial stretching of polymer films, and an Atomic Force Microscope which probes the morphological and mechanical properties of materials at the nanoscale. The Molecular Modeling Center provides access to various software packages for the rheological and molecular modeling of polymers.

Faculty

David Schiraldi, PhD
(University of Oregon)

Professor and Chair

Advanced composites based on aerogels and nanofillers, monomer and polymer synthesis, structure-property relationships, polymer degradation, polymerization catalysis, synthetic fibers, barrier packaging materials.

Rigoberto C. Advincula, PhD
(University of Florida)

Professor and Associate Chair

Design and synthesis of nanostructured materials, dendrimers, polymer brushes, thin films, and the use of innovative surface characterization techniques. Applications in electro-optical devices, sensors, biomaterials, and smart coatings.

Eric Baer, DEng
(Johns Hopkins University)

Director, Centered for Layered Polymeric Systems (CLiPS) and Herbert Henry Dow Professor of Science and Engineering

Multilayered and ultrathin polymer films and devices. 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

Liming Dai, PhD
(Australian National University)

Kent Hale Smith Professor

Multifunctional nanomaterials; optoelectronic macromolecules; and biomaterials and bioinspiration

Hatsuo Ishida, PhD
(Case Western Reserve University)

Professor

Processing of polymers and composite materials; structural analysis of surfaces and interfaces; molecular spectroscopy of synthetic polymers

Alexander M. Jamieson, DPhil
(Oxford University, England)

Professor

Quasielastic laser light scattering; relaxation and transport of macromolecules in solution and bulk; structure-function relationships of biological macromolecules

LaShanda T. Korley, PhD
(Massachusetts Institute of Technology)

Assistant Professor

Structure-function relationships; toughening mechanisms in segmented copolymers; spatial confinement of self-assembled materials, including biomaterials; hierarchical microstructures

João Maia, PhD
(University of Wales Aberystwyth, U.K.)

Associate Professor

Polymer rheology: extensional rheology and rheometry; micro- and nano-rheology; bio-rheology: food rheology and processing; rheology for macromolecular technology: development and optimization of polymer blends and composites; viscoelasticity of micro- and nano-layered polymer films; on- and in-line monitoring of extrusion-based processes; micro-processing; environmental rheology and processing

Ica Manas-Zloczower, DSc
(Israel Institute of Technology)

Professor and Associate Dean of Faculty Development

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

John Pokorski, PhD
(Northwestern University)

Assistant Professor

Biomaterials for delivery of therapeutic proteins; protein-polymer conjugates; drug-delivery; biopolymer catalysts; self-assembling peptides; affinity-based delivery of therapeutics; layered polymeric delivery systems

Stuart Rowan, PhD
(University of Glasgow, UK)

Kent Hale Smith Professor

Organic chemistry, synthesis, supramolecular chemistry, conducting polymers, interlocked macromolecules (polyrotaxanes and polycatenanes), peptide nucleic acids, supramolecular polymerization, reversible 'dynamic' chemistry and combinatorial libraries

Gary Wnek, PhD
(University of Massachusetts, Amherst)

The Joseph F. Toot, Jr., Professor of Engineering and Faculty Director, The Institute for Management and Engineering (TiME)

Polymers with unusual electrical or optical properties; biomaterials for tissue engineering and regenerative medicine; electric field-mediated processing (electrospinning of nano- and micro fibers and morphology modulation in polymer blends); polymer-based microfluidic platforms; polymer product design

Lei Zhu, PhD
(University of Akron)
Associate Professor

Nanoscale structure and morphology of crystalline/liquid crystalline polymers and block copolymers; ferroelectric and dielectric polymers for electric energy storage; polymer/inorganic hybrid nanocomposites; biodegradable polymers for diagnostic and drug delivery

Emeriti Faculty

John Blackwell, PhD
(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

Jack L. Koenig, PhD
(University of Nebraska, Lincoln)
The Donnell Institute Professor Emeritus

Polymer structure-property relationships using infrared, Raman, NMR spectroscopy and spectroscopic imaging techniques

Jerome B. Lando, PhD
(Polytechnic Institute of Brooklyn)
Professor Emeritus

Solid state polymerization; X-ray crystallography of polymers; electrical properties of polymers; ultra-thin polymer films

Morton H. Litt, PhD
(Polytechnic Institute of Brooklyn)
Professor Emeritus

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

Secondary Faculty

James M. Anderson, PhD
(Oregon State University, M.D.)
Professor of Macromolecular Science, Pathology, and Biomedical Engineering

Biocompatibility, inflammation, foreign body reaction to medical devices, prostheses, and biomaterials

Donald Feke, PhD
(Princeton University)
Professor of Chemical Engineering and Macromolecular Science
Fine-particle processing, colloidal phenomena, dispersive mixing, and acoustic separation methods

Roger French, PhD
(Massachusetts Institute of Technology)
F. Alex Nason Professor of Materials Science
Optical materials and elements, optical properties and electronic structure of materials, and electrodynamic van der Waals-London dispersion interactions

Erin Lavik, PhD
(Massachusetts Institute of Technology)
Elmer Lincoln Lindseth Associate Professor in Biomedical Engineering
Development of new approaches to understand and treat injuries and to diseases of the spinal cord, optic nerve, and retina

J. Adin Mann Jr., PhD
(Iowa State University)
Professor of Chemical Engineering
Surface phenomena, interfacial dynamics, light scattering, and stochastic processes of adsorption and molecular rearrangement at interfaces

Roger Marchant, PhD
(Case Western Reserve University)
Professor of Biomedical Engineering
Biopolymers, polymer surface coatings, and properties and characterization of polymer surfaces on implants and sensors

John Protasiewicz, PhD
(Cornell University)
Professor of Chemistry
Inorganic, organic, main group, materials, polymer, catalysis, organometallic chemistry, and X-ray crystallography

Syed Qutubuddin, PhD
(Carnegie-Mellon University)
Professor of Chemical Engineering
Surfactant and interfacial phenomena in nanomaterials including microemulsions, nanoparticles and polymer nanocomposites

Charles Rosenblatt, PhD
(Harvard University)
Professor of Physics
Experimental condensed matter physics and liquid crystal physics

Kenneth Singer, PhD
(University of Pennsylvania)
Professor of Physics
Modern optics and condensed matter experiment and nonlinear optics

Philip Taylor, PhD
(Cambridge University, England)
Perkins Professor of Physics
Phase transitions and equations of state for crystalline polymers; piezoelectricity and pyroelectricity

Horst von Recum, PhD
(University of Utah, Salt Lake City)
Assistant Professor of Biomedical Engineering
Novel platforms for the delivery of molecules and cells and the use of novel stimuli-responsive polymers for use in gene and drug delivery

Adjunct Faculty

Scott E. Rickert, PhD
(Case Western Reserve University)
Adjunct Professor
Conducting polymers; microdevices; polymer electrodes; polymer adsorption

Alan Riga, PhD
(Case Western Reserve University)

Adjunct Full Professor

Extensive industrial and forensic science experience in laboratory testing and characterization of materials, pharmaceuticals, excipients, proteins, metals, alloys, polymers, biopolymers, elastomers, organic chemicals, monomers, resins, thermosets, and thermoplastics

Christoph Weder, DrScNat
(ETH Zurich Switzerland)

Adjunct Full Professor

Design, synthesis and investigation of structure-property relationships of novel functional polymers: polymers with unusual optic and/or electronic properties; (semi)conducting conjugated polymers; stimuli-responsive polymers; biomimetic materials, polymer nanocomposites, supramolecular chemistry.

Courses

EMAC 125. Freshman Research on Polymers. 1 Unit.

Freshman research in polymer chemistry, engineering, and physics. Students will be placed in active research groups and will participate in real research projects under the supervision of graduate students and faculty mentors.

EMAC 270. Introduction to Polymer Science and Engineering. 3 Units.

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. Recommended preparation: ENGR 145.

EMAC 276. Polymer Properties and Design. 3 Units.

The course reviews chemical and physical structures of a wide range of applications for synthetic and natural polymers, and addresses "Which polymer do we choose for a specific application and why?" We examine the polymer properties, the way that these depend on the chemical and physical structures, and reviews how they are processed. We aim to understand the advantages and disadvantages of the different chemical options and why the actual polymers that are used commercially are the best available in terms of properties, processibility and cost. The requirements include two written assignments and one oral presentation. Recommended preparation: ENGR 145. Counts as SAGES Departmental Seminar.

EMAC 303. Structure of Biological Materials. 3 Units.

Structure of proteins, nucleic acids, connective tissue and bone, from molecular to microscopic levels. An introduction to bioengineering biological materials and biomimetic materials, and an understanding of how different instruments may be used for imaging, identification and characterization of biological materials. Offered as: EBME 303 and EMAC 303. Recommended preparation: EBME 201, EMBE 202, and EMAC 270.

EMAC 325. Undergraduate Research in Polymer Science. 1 - 3 Unit.

Undergraduate laboratory research in polymer chemistry/physics/engineering. Students will undertake an independent research project, working under the mentoring of both a graduate student and a faculty member. A mid-term written progress report is required. A written report and oral presentation will be made at the end of the semester. Can be taken for 1-3 credits per semester, up to a total of 6 credit hours. Students are expected to spend approximately 5 hours/week in the laboratory per credit registered each semester. Recommended preparation: Sophomore/Junior standing and consent of instructor.

EMAC 351. Physical Chemistry for Engineering. 3 Units.

Principles of physical chemistry and their application to systems involving physical and chemical transformations. The nature of physical chemistry, properties of gases, overview of the laws of thermodynamics, thermochemistry, solutions, phases and chemical equilibrium, kinetics of chemical reaction, solutions of electrolytes and introduction to quantum mechanics, atomic structure and molecular statistics. Recommended preparation: ENGR 225, PHYS 122.

EMAC 352. Polymer Physics and Engineering. 3 Units.

Single chain statistics and thermodynamics of dilute polymer solutions (single chain statistics, Flory-Kringbaum theory, vapor pressure and osmotic pressure, light, small angle X-Ray, and small-angle neutron scattering), solid state properties of polymers (polymer viscoelasticity (time-temperature superposition; rubber thermodynamics and statistics), glasses and related mechanical properties (fracture mechanism), crystals and liquid crystals; structure property relationship, polymer blends, block copolymers and composites, transport phenomena (conservation of mass, momentum and energy, differential forms, integral forms, momentum transport, laminar and turbulent flow, Navier-Stokes equation, mass transport, diffusion, Fick's law) and transport phenomena of polymer solutions (intrinsic viscosity, sedimentation and diffusion, dynamic light scattering, polyelectrolytes and block copolymers in solution, size exclusion chromatography). Prereq: EMAC 351

EMAC 355. Polymer Analysis Laboratory. 3 Units.

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. Recommended preparation: EMAC 270 or MATH 224 or MATH 234.

EMAC 370. Polymer Chemistry. 3 Units.

The fundamentals of organic chemistry of polymer synthesis, suitable for laboratory and industrial polymer production. Prereq: EMAC 270.

EMAC 372. Polymer Processing and Testing Laboratory. 3 Units.

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. Recommended preparation: EMAC 377.

EMAC 375. Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology. 3 Units.

This course will involve the study of Rheology from the perspectives of rheological property measurement, phenomenological and molecular models, and applicability to polymer processing. In particular, students will be introduced to: 1) General concepts of Rheology and Newtonian Fluid Mechanics, 2) Standard flows and material functions; 3) The role of Rheology as a structural characterization tool, with an emphasis on polymeric systems; 4) Experimental methods in Rheology with quantitative descriptions of associated flows and data analyses; 5) Viscoelasticity and Non-Newtonian Fluid Mechanics, including the application of models, both phenomenological and molecular, to the prediction of rheological behavior and extraction of model parameters from real data sets; and 6) The relevance of rheological behavior of different systems to practical processing schemes, particularly with respect to plastics manufacturing. Offered as EMAC 375 and EMAC 475. Prereq: ENGR 225 or EMAC 404.

EMAC 376. Polymer Engineering. 3 Units.

Mechanical properties of polymer materials as related to polymer structure and composition. Visco-elastic behavior, yielding and fracture behavior including irreversible deformation processes. Recommended preparation: EMAC 276 and ENGR 200. Offered as EMAC 376 and EMAC 476.

EMAC 377. Polymer Processing. 3 Units.

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. Recommended preparation: ENGR 225.

EMAC 378. Polymer Engineer Design Product. 3 Units.

Uses material taught in previous and concurrent courses in an integrated fashion to solve polymer product design problems. Practicality, external requirements, economics, thermal/mechanical properties, processing and fabrication issues, decision making with uncertainty, and proposal and report preparation are all stressed. Several small exercises and one comprehensive process design project will be carried out by class members. Offered as EMAC 378 and EMAC 478. Counts as SAGES Senior Capstone.

EMAC 396. Special Topics. 1 - 18 Unit.

(Credit as arranged.)

EMAC 398. Polymer Science and Engineering Project I. 1 - 3 Unit.

(Senior project). Research under the guidance of faculty. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Repeatable up to 3 credit hours. When taken for 3 credits it may be spread over two successive semesters. Recommended preparation: Senior standing. Counts as SAGES Senior Capstone.

EMAC 399. Polymer Science and Engineering Project II. 1 - 9 Unit.

(Senior project.) Research under the guidance of staff, culminating in thesis. Recommended preparation: Majors only and senior standing.

EMAC 400T. Graduate Teaching I. 0 Units.

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. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 401. Polymer Foundation Course I: Organic Chemistry. 3 Units.

The class is an introduction to the synthesis and organic chemistry of macromolecules. The course introduces the most important polymerization reactions, focusing on their reaction mechanisms and kinetic aspects. Topics include free radical and ionic chain polymerization, condensation (step-growth) polymerization, ring-opening, insertion and controlled addition polymerization. There is no limit on the number of students for the class as a whole.

EMAC 402. Polymer Foundation Course II: Physical Chemistry. 3 Units.

This class is an introduction to the physical chemistry of polymers in solution. Topics include: polymer statistics: (microstructure, chain configuration, and chain dimensions), thermodynamics and transport properties of polymers in solution, methods for molecular weight determination, physical chemistry of water-soluble polymers, and characterization of polymer microstructure (IR and NMR). There is no limit on the number of students for the class as a whole.

EMAC 403. Polymer Foundation Course III: Physics. 3 Units.

This class is an introduction to the physics of polymers in the bulk amorphous and crystalline states. Topics include: structural and morphological analysis using X-ray diffraction, electron microscopy and atomic force microscopy, characterization of thermal transitions, viscoelastic behavior and rubber elasticity, and dynamic mechanical analysis. There is no limit on the number of students for the class as a whole.

EMAC 404. Polymer Foundation Course IV: Engineering. 3 Units.

This class is an introduction to the engineering and technology of polymeric materials. Topics include: additives, blends and composites, natural polymers and fibers, thermoplastics, elastomers, and thermosets, polymer degradation and stability, polymers in the environment, polymer rheology and polymer processing, and polymers for advanced technologies (membrane science, biomedical engineering, applications in electronics, photonic polymers). There is no limit on the number of students for the class as a whole.

EMAC 405. Polymer Characterization Laboratory. 3 Units.

Laboratory experience through synthesis and characterization of polymers. Synthesis via addition and condensation polymerization. Characterization methods include size exclusion chromatography, infrared and NMR spectroscopy. Solid samples are characterized by x-ray diffraction, electron microscopy, thermal analysis, and physical properties. Fluid samples are characterized by melt rheology. Prereq: EMAC 401, EMAC 402, EMAC 403 and EMAC 404.

EMAC 410. Polymers Plus Self - Assembly and Nanomaterials. 2 Units.

The course focuses on the concepts of supramolecular chemistry and self-assembly specifically as it applies to nano-polymeric systems. After dealing with many of the fundamental aspects of supramolecular chemistry the focus of the class deals with how to access/utilize nano-scale features using such processes, namely the 'bottom-up' approach to nanomaterials/systems. Areas which will be addressed include block copolymers, DNA assemblies, nanotubes and dendrimers. Prereq: EMAC 401 or EMAC 370.

EMAC 412. Polymers Plus Inorganic/Coordination Chemistry. 2 Units.

The course focuses on the concepts of inorganic and coordination chemistry specifically as they apply to polymeric systems. The fundamental aspects of coordination chemistry, including coordinative saturation, kinetics and mechanism will be presented and used as a vehicle to describe coordination polymerizations and supramolecular coordination phenomena. The chemistry and physics of nanoscale inorganic modification of polymers by clays, silsesquioxanes, metal oxides and metal particles will also be discussed. Prereq: EMAC 401 or EMAC 370.

EMAC 413. Polymers Plus Green Chemistry and Engineering. 2 Units.

This course focuses on green chemistry and engineering, particularly as it relates to polymers. Specific topics to be covered in this course will include green chemistry, catalysis, alternative solvents, green processing, renewable materials, and life cycle analysis. Case studies will be utilized to connect lecture topics to real-world examples. Prereq: EMAC 401 and EMAC 404.

EMAC 414. Polymers Plus Advanced Composite and Nanocomposite Materials and Interfaces. 2 Units.

"Advanced Composite and Nanocomposite Materials and Interfaces" will aim at providing advanced concept in composite material structures, importance of interface on the property development, rheological background to be able to manufacture optimized materials, and appropriate processing techniques to choose for a specific product to be manufactured. Specifically, this course will discuss the following items: 1. Basic concept of heterogeneous materials including advantages and problems associated with making multiphase materials. 2. It will review broadly the materials used to make composites and nanocomposites. 3. Unique properties of composites/nanocomposites in rheological, mechanical, and physical properties will be discussed. 4. Various composite processing techniques will be discussed in detail. 5. Surface treatment of the reinforcing materials and interface/interphase structures of composites/nanocomposites will be discussed.

EMAC 415. Polymers Plus Structure and Morphology. 2 Units.

This special topic focuses on polymer structure and morphology and their applications. Topics include solid-state physics of various polymeric materials, ranging from crystalline polymers to liquid crystalline polymers, and block copolymers. First, symmetry operation, space groups, reciprocal spaces are introduced. Examples of the crystalline structures of industrially important polymers and typical polymer crystalline morphology such as lamellar and spherulitic crystals are discussed. Defects in crystalline polymer is also an important issue that determines their physical properties. Second, typical phase structure and transitions of liquid crystals and liquid crystalline polymers are introduced, including both thermotropic and lyotropic liquid crystals. Finally, nanostructure and morphology of block copolymers are discussed. Prereq: EMAC 402 and EMAC 403.

EMAC 416. Polymers Plus Applied Rheology and Processing. 2 Units.

This course focuses on the applications of Rheology to Polymer Engineering in general and processing technologies in particular. It starts with a general review of rheological concepts, including viscoelasticity and continues with the influence of shear rate, temperature, and pressure on the rheological properties. Next, the role of Rheology in support of polymer processing, including effects and defects of rheological origin will be analyzed; here the focus will be on the most common processing techniques - extrusion, injection molding, blow-molding, and thermoforming. Finally, there will be a brief introduction of the role of Rheology in the structural characterization of polymeric materials. Prereq: EMAC 376 or graduate standing.

EMAC 417. Functional Polymers. 2 Units.

Polymers have traditionally been used for the so-called passive applications in many areas, ranging from engineering materials to electronics devices. Various functional polymers have now been synthesized with unusual electronic, optical, and mechanical properties. These properties allow polymers to be used as active components for various applications, where they play an active role in regulating the property of materials and performance of devices. Examples include, but not limited to, polymer sensors, polymer actuators, polymer light-emitting diodes, and polymer photovoltaic cells. The objective of this proposed course is to provide polymer engineering and polymer science students with the recent development in functional polymers and their device-related applications. Course Outline: 1). The Concept of Functional Polymers (0.5 week) 2). Electronically Active polymers (1 weeks) - Synthesis, Structure, Conduction Mechanism, and Property 3). Optically Active Polymers (1.5 weeks): Light-Emitting Polymers, Photovoltaic Polymers, Non-Linear Optical Polymers 4). Stimuli-Responsive Polymers (2 weeks): Solvent/Temperature/pH Responsive Polymers, Field Responsive Polymers 5). Functional Polymers for Device Applications (2 weeks): Polymer Sensors and Actuators, Plastic Electronics, Polymer Light-Emitting Diodes and Photovoltaic Cells, Polymeric Biomedical Devices

EMAC 421. Polymer Plus Hierarchical Structures and Properties. 2 Units.

Discuss the hierarchical solid state structure of synthetic and naturally occurring polymeric systems and relate these structures to their properties. Particular emphasis will be on natural systems containing collagen(s) and carbohydrate(s), and on synthetic crystalline, liquid crystalline, and reinforced composite polymeric materials. In order to prepare students for application of these concepts we will determine how mechanical, transport and optical (photonic) behavior can be controlled by structure manipulation. Prereq: EMAC 403 and EMAC 404 or EMAC 474 or EMAC 476.

EMAC 422. Polymers Plus Microscopy. 2 Units.

This course focuses on application of microscopy techniques to the analysis of the microstructure of polymeric materials. Specifically, atomic force microscopy, transmission and scanning electron microscopy, and optical microscopy will be discussed. Practical aspects of these techniques will be applied to a variety of systems, including block copolymers, nanocomposites, LC polymers, and multi-layered films. Prereq: EMAC 403 or EMAC 474.

EMAC 423. Polymers Plus Adhesives, Sealants and Coatings. 2 Units.

An introduction to the technology of adhesives, sealants and coatings. Relevant adhesion theories and practices. Resin Structure and Reactivity. Principles of film formation and rheology control. Pigment Dispersion and Color Measurement. Test methods for mechanical properties and durability. Materials technology to comply with environmental regulations. Prereq: EMAC 402 or EMAC 370.

EMAC 425. Polymer Plus Energy. 2 Units.

Energy research has become the focus of the twenty-first century. This course is a special topic on polymers in the energy field and related applications. We primarily focus on polymers for solar cells, fuel cells, batteries, double layer electrochemical capacitors, dielectric capacitors, and wind energy. For solar cells, we will introduce conducting polymers and basic types of polymer solar cells. For fuel cells, we will introduce both proton- and hydroxide-exchange fuel cells. Fundamental issues of ion transport, water management, and fuel cell longevity will be introduced. For supercapacitors, we will introduce porous carbon structures and charge storage mechanism. For dielectric capacitors, we will introduce fundamental concepts in electrostatics, different types of polarization, and loss mechanism. For wind energy, we will introduce polymer composites for wind blades and polymer coatings. This course will combine lectures and contemporary literature reviews/essays.

EMAC 426. Biopolymers: Structure, Synthesis, and Application in Medicine. 2 Units.

An introduction to biomacromolecules including DNA, RNA, and proteins. The course will deal with the synthesis and manipulation of biological and synthetic macromolecules as it applies to topics in modern medicine. Topics covered will include nanoparticle gene and drug delivery systems, polymer hydrogels, polymer imaging agents, and protein-polymer conjugates. The purpose of this course is to provide a survey of important areas in medicine where a polymer chemist/engineer can intervene to make a meaningful contribution. Prereq: CHEM 323 and CHEM 324.

EMAC 427. Polymers Plus a Sustainable Economy. 2 Units.

This course is an interdisciplinary seminar-based course surveying the diverse roles played by polymers in a sustainable economy. Specific topics for discussion include: (i) Renewable Energy and the Sustainable Economy; (ii) Renewable Polymers and the Sustainable Economy; (iii) Challenges for Biotechnology in the Sustainable Economy; (iv) Lifetime Analysis of Polymers; Green Policy in the Sustainable Economy; (v) Sustainable Product Innovation in Northeast Ohio; (vi) Advanced Manufacturing for a Sustainable Economy in Northeast Ohio; (vii) Eco-conscious business models in the polymer industry (viii) Bioethics in Biotechnology; (ix) Alternative Solvents and Processing; and (x) Polymers for Energy Storage and Delivery. Prereq: EMAC 401 and EMAC 404.

EMAC 450. The Business of Polymers. 2 Units.

This course will link polymer technology to business and management issues that need to be considered for successful technology commercialization. Topics include project management, finance, opportunity assessment, the voice of the customer, and protection of intellectual property. Case studies from both large and small companies will be used to illustrate key concepts. Recommended preparation: EMAC 270, EMAC 276.

EMAC 451. Polymer Product Design. 2 Units.

This course introduces the fundamentals of successful product design and development with specific attention to products based on polymeric materials. Topics covered include the voice of the customer, idea generation and screening, concept selection, prototyping, manufacturing, marketing, and launch. The importance of good design beyond simple form and function will be stressed. Each student will complete a product design portfolio that considers all of these issues. Recommended preparation: EMAC 270, EMAC 276, EMAC 450.

EMAC 461. Chemistry of Fire Safe Polymers and Composites. 3 Units.

Chemistry of Fire Safe Polymers and Composites starts with the introduction of characterization techniques used for fire safe materials and combustion phenomena research. General discussion on how reduced flammability of polymers and composites are obtained, for example by additives and preparing intrinsically thermally stable chemical structure and some examples of smart approaches, will be discussed. It also discusses the synthetic methods of preparing high temperature stable polymers in addition to the raw materials used to prepare those materials. Special emphasis will be placed on the thermal stability data obtained by thermogravimetric analysis (TGA) and combustion calorimetry for those fire safe materials. Mechanistic aspects of the flammability of polymers will be explained with special emphasis on the molar contribution of chemical functionality to the heat release capacity. Theoretical derivation of thermokinetic parameters will be explained. In addition, a common sense build-up will be attempted by providing actual numbers associated with those thermokinetic parameters. Upon completion of background formation, a more advanced materials, composites and nanocomposites, will be discussed using the results recently reported. Preliminary attempts to explain flame retardation by nanocomposite structures will also be discussed. Offered as EMAC 461 and EMAE 461.

EMAC 471. Polymers in Medicine. 3 Units.

This course covers the important fundamentals and applications of polymers in medicine, and consists of three major components: (i) the blood and soft-tissue reactions to polymer implants; (ii) the structure, characterization and modification of biomedical polymers; and (iii) the application of polymers in a broad range of cardiovascular and extravascular devices. The chemical and physical characteristics of biomedical polymers and the properties required to meet the needs of the intended biological function will be presented. Clinical evaluation, including recent advances and current problems associated with different polymer implants. Recommended preparation: EBME 306 or equivalent. Offered as EBME 406 and EMAC 471.

EMAC 475. Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology. 3 Units.

This course will involve the study of Rheology from the perspectives of rheological property measurement, phenomenological and molecular models, and applicability to polymer processing. In particular, students will be introduced to: 1) General concepts of Rheology and Newtonian Fluid Mechanics, 2) Standard flows and material functions; 3) The role of Rheology as a structural characterization tool, with an emphasis on polymeric systems; 4) Experimental methods in Rheology with quantitative descriptions of associated flows and data analyses; 5) Viscoelasticity and Non-Newtonian Fluid Mechanics, including the application of models, both phenomenological and molecular, to the prediction of rheological behavior and extraction of model parameters from real data sets; and 6) The relevance of rheological behavior of different systems to practical processing schemes, particularly with respect to plastics manufacturing. Offered as EMAC 375 and EMAC 475. Prereq: ENGR 225 or EMAC 404.

EMAC 477. Elementary Steps in Polymer Processing. 3 Units.

This course is an application of principles of fluid mechanics and heat transfer to problems in polymer processing. In the first part of the course, basic principles of transport phenomena will be reviewed. In the second part, the elementary steps in polymer processing will be described and analyzed with application to a single screw extruder.

EMAC 478. Polymer Engineer Design Product. 3 Units.

Uses material taught in previous and concurrent courses in an integrated fashion to solve polymer product design problems. Practicality, external requirements, economics, thermal/mechanical properties, processing and fabrication issues, decision making with uncertainty, and proposal and report preparation are all stressed. Several small exercises and one comprehensive process design project will be carried out by class members. Offered as EMAC 378 and EMAC 478. Counts as SAGES Senior Capstone.

EMAC 480. Writing an NSF-Style Scientific Proposal. 2 Units.

The aim of this course is to learn how to develop a National Science Foundation (NSF) grant proposal. The class will include all aspects of building an NSF proposal from the intellectual Merit of the scientific content to its Broader impacts. It will also focus on how to put together the other aspects required for an NSF proposal, such as budget, facilities, NSF-style bio, etc. The class will involve some lectures on the basics of putting the proposal together (best practices, etc.) followed by writing the NSF proposal using the NSF's current Grant Proposal Guide (GPG). The class will meet once a week to discuss the progress of each of the student's proposals. The students will be expected to come up with their own polymer-related scientific idea for the grant proposal (which has to be approved by the Macromolecular Sci & Eng Graduate Committee before the end of the second week of class). Toward the end of the class all proposals will be evaluated by the students (each student will be assigned as a primary reviewer for some of the proposals, a secondary reviewer and a scribe for others). The class will then hold a NSF-style proposal panel review. Each proposal will be awarded an NSF evaluation grade (Excellent, Very Good, Good, Fair, Poor) and a final review report for each proposal will be drafted by the students. The final grade for this class depends on the quality of the proposal as well as the students' participation in the NSF-style panel review process.

EMAC 490. Polymers Plus Professional Development. 1 Unit.

This course focuses on graduate student professional development. The course involves weekly meetings and oral presentations with attention on the content and style of the presentation materials (PowerPoint, posters, etc.), oral presentation style and project management skills. This course can be taken for the total of 3 credits over three different semesters.

EMAC 491. Polymers Plus Literature Review. 1 Unit.

This course involves weekly presentations of the current polymer literature. It involves at least one presentation by the enrolled student and participation in all literature reviews (at least 10/semester). The course will focus on presentation skills (both oral and written), scientific interpretation, and development of peer-review skills. This course can be taken for a total of 3 credits over three different semesters.

EMAC 492. Carbon Nanoscience and Nanotechnology. 3 Units.

This course presents the fundamental aspects of nanoscience and nanotechnology with an emphasis on carbon nanomaterials and nanodevices. This proposed course intends to provide students with the fundamental aspects of nanoscience and nanotechnology. Nanotechnology draws on the strengths of all the basic sciences and is the engineering at the molecular level, which has the potential to lead to novel scientific discoveries as well as new industrial technologies. This course will give students insight into a new, exciting and rapidly developing field. The course has a good balance between basic knowledge and depth with a focus on some key application areas, which will enable students to work in a variety of scientific professions.

EMAC 500T. Graduate Teaching II. 0 Units.

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. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 600T. Graduate Teaching III. 0 Units.

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. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 601. Independent Study. 1 - 18 Unit.

(Credit as arranged.)

EMAC 651. Thesis M.S.. 1 - 18 Unit.

(Credit as arranged.)

EMAC 673. Selected Topics in Polymer Engineering. 2 - 3 Units.

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. Recommended preparation: EMAC 376 or EMAC 476.

EMAC 677. Colloquium in Macromolecular Science and Engineering. 0 - 1 Units.

Lectures by invited speakers on subjects of current interest in polymer science and engineering. This course can be taken for 3 credits over three different semesters.

EMAC 690. Special Topics in Macromolecular Science. 1 - 18 Unit.**EMAC 701. Dissertation Ph.D.. 1 - 18 Unit.**

(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

EMAC C200. Co-op Seminar II for Macromolecular Science and Engineering. 2 Units.

Professional development activities for students returning from cooperative education assignments. Recommended preparation: COOP 002 and EMAC C100.

Department of Materials Science and Engineering

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, polymers, 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.

While an engineering discipline, the field brings basic science tools to bear on the technological challenges related to materials products and their manufacture. 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, optical, magnetic and electrical properties of materials, as well as the tools needed to ascertain the structure and properties of materials. Mathematical simulations of materials manufacturing processes, computational modeling of fundamental materials science phenomena, and computer programs for materials design and microstructural analysis are examples of the growing importance of mathematics in materials science and engineering.

Undergraduate Programs

The curriculum leading to the degree of Bachelor of Science in Engineering, Major 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, which also allow students to choose one of several areas of concentration within the major. A total of 129 credit hours is required. Please see the table for the recommended semester-by-semester listing of courses.

The Bachelor of Science degree program in Materials Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

Throughout the undergraduate curriculum in materials science and engineering, scientific fundamentals are integrated with coverage of current manufacturing, design, and applications of engineering materials.

The goal of the Department of Materials Science and Engineering is to prepare students for rewarding careers that provide creative, effective solutions to societal needs, through coursework and associated activities that emphasize:

- 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 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.

Program Educational Objectives

1. Graduates will successfully enter and complete graduate and professional degree programs.
2. Graduates will assume leadership positions in materials science related industries.
3. Graduates will be effectively involved in solving technical problems.
4. Graduates will take an active part in professional organizations.

Student Outcomes

As preparation for achieving the above educational objectives, the BS degree program in Materials Science and Engineering is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Program Outcomes

- 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.
 - 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.
 - Graduates will be proficient in the oral, written, and electronic communication of their ideas.
 - Graduates will be proficient in the use of computer technology and computer-based information systems.
 - Graduates will be able to function effectively in groups of peers and independently.
 - Graduates will be informed of the impact of engineering on society and of the professional, ethical, safety, and environmental responsibilities that that entails.
 - Graduates will regard professional development and education as processes that should continue hand-in-hand throughout their academic and professional careers.
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Bachelor of Science in Engineering

Major in Materials Science and Engineering

EMSE 110	Transitioning Ideas to Reality I - Materials in Service of Industry and Society	1
EMSE 120	Transitioning Ideas to Reality II - Manufacturing Laboratory	2
EMSE 220	Materials Laboratory I	2
EMSE 228	Mathematical Methods for Materials Science and Engineering	3
EMSE 276	Materials Properties and Design	3
EMSE 319	Processing and Manufacturing of Materials	3
EMSE 320	Materials Laboratory II	1
EMSE 327	Thermodynamic Stability and Rate Processes	3
EMSE 328	Meso-scale Science Including Nanotechnology	3
EMSE 330	Materials Laboratory III	2
EMSE 343	Materials for Electronics and Photonics	3
EMSE 345	Materials for Biological and Medical Technology	3
EMSE 349	Materials for Energy and Sustainability	3
EMSE 372	Structural Materials by Design	4
EMSE 379	Design for Lifetime Performance	3
EMSE 398	Senior Project in Materials I	1
EMSE 399	Senior Project in Materials II	2
Related Required Courses		
EMAC 276	Polymer Properties and Design	3
EMAC 376	Polymer Engineering	3
Total Units		48

Concentrations

The undergraduate program includes courses that expose students to greater depth in areas related to materials science and engineering. These concentration sequences are of two types:

- Students may select an area of concentration that is based on an application or subfield of engineering materials. Each concentration will be a coherent set of courses that, in conjunction with one or more of the courses already required for all EMSE majors plus a specified mathematics/natural science/statistics course, will provide significant depth in an area of materials specialization.
- Students also have the option of designing a concentration — Advanced Materials Science and Engineering — in consultation with their advisors and subject to approval by the department's Undergraduate Studies Committee.

The proposed concentrations are below. All concentrations equal 12 credit hours (four courses).

Biomaterials

EBME 201	Physiology-Biophysics I *	3
EBME 202	Physiology-Biophysics II *	3

Plus two of the following:

EBME/EMAC 303	Structure of Biological Materials	
EBME 305	Materials for Prosthetics and Orthotics	
EBME 306	Introduction to Biomedical Materials	
EBME 315	Applied Tissue Engineering	

EBME 316	Biomaterials for Drug Delivery	
EBME 325	Introduction to Tissue Engineering	
EBME 406/ EMAC 471	Polymers in Medicine	
EBME/EECS 480B	The Human Body	
EMSE 425	Biomolecular Materials Science	

Electronic Materials

PHYS 221	Introduction to Modern Physics *	3
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Plus three of the following (from either or both categories):

Emphasis on solid state physics:		
PHYS 315	Introduction to Solid State Physics	
PHYS 326	Physical Optics	
PHYS 327	Laser Physics	
PHYS 331	Introduction to Quantum Mechanics I	
Emphasis on electronic device technology:		
CHEM 340	Solar Energy Conversion	
ECHE 383	Chemical Engineering Applied to Microfabrication and Devices	
EECS 309	Electromagnetic Fields I	
EECS 321	Semiconductor Electronic Devices	
EECS 322	Integrated Circuits and Electronic Devices	
EMSE 405	Dielectric and Electrical Properties of Materials	
EMSE 406	Optical Materials, Elements and Technologies	
EMSE 426	Semiconductor Thin Film Science and Technology	
EMSE 427	Dislocations in Solids	
EMSE 463	Magnetism and Magnetic Materials	

Polymers

CHEM 223	Introductory Organic Chemistry I *	
or		
CHEM 323	Organic Chemistry I *	

Plus three of the following:

EMAC 270	Introduction to Polymer Science and Engineering	
EMAC 351	Physical Chemistry for Engineering	
EMAC 355	Polymer Analysis Laboratory	
EMAC 372	Polymer Processing and Testing Laboratory	
EMAC 375	Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology	
EMAC 377	Polymer Processing	

Completion of this concentration (including EMAC 276 and EMAC 376, as required for the major in Materials Science and Engineering) satisfies the requirements for a minor in Polymer Science and Engineering.

Structural Materials and Mechanical Behavior

STAT 312	Basic Statistics for Engineering and Science *	3
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Plus three of the following:

ECIV 211	Civil Engineering Materials	
ECIV 310	Strength of Materials	
EMAE 370	Design of Mechanical Elements	
EMAE 378	Mechanics of Machinery I	
EMSE 417	Properties of Materials in Extreme Environments	

EMSE 421	Fracture of Materials
EMSE 422	Failure Analysis
EMSE 427	Dislocations in Solids
EMAE 480	Fatigue of Materials

* Satisfies the Mathematics/Science/Statistics requirement of the Case School of Engineering.

Advanced Materials Science and Engineering

Students may satisfy the concentration requirement by taking nine credits of EMSE courses (beyond those specifically required in the curriculum) at the 300 level or above, plus a course to satisfy the Mathematics/Natural Sciences/Statistics requirement in the Engineering Core. The courses are to be selected in consultation with the student's advisor and will be subject to approval by the department's Undergraduate Studies Committee. This option is suitable for students who wish to pursue graduate studies in materials science and engineering and is compatible with the BS/MS program in the Case School of Engineering. This option is also appropriate for students who desire further study in a branch of materials science and engineering that is not represented by the four specializations listed above.

Bachelor of Science in Engineering

Suggested Program of Study: Major in Materials Science and Engineering

First Year	Units	
	Fall	Spring
SAGES First year Seminar	4	
PHED 1xx Physical Education Activities		
Transitioning Ideas to Reality I - Materials in Service of Industry and Society (EMSE 110)	1	
Calculus for Science and Engineering I (MATH 121)	4	
Principles of Chemistry for Engineers (CHEM 111)	4	
Elementary Computer Programming (ENGR 131) or Introduction to Programming in Java (EECS 132)	3	
General Physics I - Mechanics (PHYS 121) or Physics and Frontiers I - Mechanics (PHYS 123)	4	
Transitioning Ideas to Reality II - Manufacturing Laboratory (EMSE 120)	2	
Chemistry of Materials (ENGR 145) (or EMSE 146 Principles and Applications of Materials Chemistry)	4	
SAGES University Seminar I	3	
Calculus for Science and Engineering II (MATH 122)	4	
PHED 1xx Physical Education Activities		
Year Total:	16	17
Second Year	Units	
	Fall	Spring
General Physics II - Electricity and Magnetism (PHYS 122) or Physics and Frontiers II - Electricity and Magnetism (PHYS 124)	4	
Materials Properties and Design (EMSE 276)	3	
Mathematics/Natural Science/Statistics ¹	3	
SAGES University Seminar 2	3	

Calculus for Science and Engineering III (MATH 223) or Calculus III (MATH 227)	3	
Humanities/Social Science I	3	
Elementary Differential Equations (MATH 224) or Differential Equations (MATH 228)	3	
Statics and Strength of Materials (ENGR 200)	3	
Materials Laboratory I (EMSE 220)	2	
Mathematical Methods for Materials Science and Engineering (EMSE 228)	3	
Polymer Properties and Design (EMAC 276)	3	
Year Total:	16	17

Third Year	Units	
	Fall	Spring
Materials for Electronics and Photonics (EMSE 343)	3	
Humanities/Social Science II	3	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
Materials Laboratory II (EMSE 320)	1	
Structural Materials by Design (EMSE 372)	4	
Concentration I ¹	3	
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)	4	
Materials Laboratory III (EMSE 330)	2	
Processing and Manufacturing of Materials (EMSE 319)	3	
Thermodynamic Stability and Rate Processes (EMSE 327)	3	
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)	3	
Year Total:	15	18

Fourth Year	Units	
	Fall	Spring
Concentration II ¹	3	
Meso-scale Science Including Nanotechnology (EMSE 328)	3	
Senior Project in Materials I (EMSE 398)	1	
Humanities/Social Science III	3	
Materials for Biological and Medical Technology (EMSE 345)	3	
Materials for Energy and Sustainability (EMSE 349)	3	
Concentration III ¹	3	
Design for Lifetime Performance (EMSE 379)	3	
Humanities/Social Science IV	3	
Senior Project in Materials II (EMSE 399)	2	
Polymer Engineering (EMAC 376)	3	
Year Total:	16	14

Total Units in Sequence: 129

Hours required for graduation: 129

- ¹ Actual courses and sequence will vary depending on the concentration chosen; see "Concentrations."

Cooperative Education

The Cooperative Education program at Case Western Reserve began in the Materials Science and Engineering Department and the department's faculty continues to strongly support student participation. A wide range of opportunities exist for materials majors including large, small, and, mid-size 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.

Five-Year Combined BS/MS Program

This program offers outstanding undergraduate students the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree. (Normally, it takes two years beyond the BS to earn an MS degree.) In this program, an undergraduate student can take up to 9 credit hours that simultaneously satisfy undergraduate and graduate requirements. Students considering the combined BS/MS Program should use the Advanced Materials Science concentration, and should select their concentration in consultation with their departmental academic advisor. Typically, students in this program start their research leading to the MS 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 BS degree is awarded at the completion of the senior year.

Application for admission to the five year BS/MS program is made after completion of five semesters of course work. Minimum requirements are a 3.2 grade point average and the recommendation of a faculty member of the department. Interested students should contact Professor Peter Lagerlöf.

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 a student 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 EMSE 276 Materials Properties and Design and a minimum of 12 additional credit hours of EMSE courses, including no more than 3 credits of EMSE 125 Freshman Research in Materials Science and Engineering and EMSE 325 Undergraduate Research in Materials Science and Engineering, and no more than 6 credits of one- or two-credit courses. Professor Mark De Guire (mark.deguire@case.edu) (510 White, 368.4221) will assist EMSE minors with course selection.

Graduate Programs

The department offers programs leading to the Master of Science and Doctor of Philosophy degrees. The theory, properties, and engineering behavior of metals, ceramics, polymers, electronic materials, and composite materials is encompassed in the academic courses and

research within the department. The primary areas of specialization are materials processing, structural materials, surface and microstructural characterization, and functional materials.

MS Degree Requirements

The MS 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 with a final oral defense; this plan is appropriate for full-time graduate students. Plan B involves a major project and a final oral exam; this route is usually followed by part-time graduate students who are currently employed as materials engineers. The examining committee consists of three faculty members of the department for either Plan A or Plan B. Additional committee members may be added at the discretion of the student in consultation with his or her advisor.

Plan A requires successful completion of 6 courses (18 credit hours) and at least 9 credit hours of EMSE 651 Thesis M.S.. Plan B requires the successful completion of 8 courses (24 credit hours) as well as 3 credit hours of EMSE 649 Special Projects.

The six courses for Plan A and the eight courses for Plan B may include a maximum of two courses from an engineering or science curriculum outside the department. No more than two courses at the 300 level can be included; all other courses must be at a higher level. A cumulative GPA of 2.75 or higher is required. 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 BS degree requirements at the other university.

A planned Program of Study must be submitted by the end of the second semester for Plan A and for Plan B students. The POS should be prepared by the student and his/her advisor and submitted online to the School of Graduate Studies.

PhD Degree Requirements

Immediately upon entering the department, the PhD candidate normally will:

- Fill out and submit the first part of the Program of Study & Supplementary Form
- Register for 2 classes during the first semester
- Register for EMSE 701 Dissertation Ph.D. (usually 3 credit hours) during the first semester. Note that registration for EMSE 701 is not permitted before the Program of Study form is turned in.

As specified in the University General Bulletin section of the School of Graduate Studies: "In order to meet the requirements for the doctorate, a student must pass satisfactorily a general examination (or a series of examinations covering different fields) specified and administered by the student's department or supervising committee."

Candidates for a PhD degree in Materials Science and Engineering must pass a two-part General Exam. The first part is a Comprehensive Exam and the second part is a Thesis Proposal Evaluation.

PhD Comprehensive Exam

Full-time students are required to take the PhD Comprehensive Exam within one year for students entering with an MS degree, or within three years for students entering with a BS degree. Part-time students must complete the exam prior to accumulating ten or more credit hours. The exam will be offered twice per year at roughly six months intervals,

typically in January and June. The exam will consist of a written test covering specific areas of materials science and engineering.

The exam has multi-part questions that cover the following 4 areas:

1. Structure
2. Thermodynamics
3. Phase Transformations
4. A Specialty Area: Structural Material, Microcharacterization, or Functional Materials

The 4-hour exam requires the student to answer one question chosen from a set of three for each of areas 1, 2, and 3. The student will also choose one of the three Specialty Areas and will answer one of two questions for the selected specialty.

The department faculty recommends the following textbooks be used in preparation for the exam.

General Materials Science Books

- *Fundamentals of Materials Science: The Microstructure-Property Relationship Using Metals as Model Systems*. Eric J. Mittemeijer, 2010.
- *Thermodynamics in Materials Science*, 2nd edition. Robert DeHoff, 2006.
- *Electronic Properties of Materials*, 4th edition. Rolf E. Hummel, 2011.
- *Deformation and Fracture Mechanics of Engineering Materials*. Richard W. Hertzberg, Richard P. Vinci, Jason L. Hertzberg, 2013.

Basic Science Books

- *Intermolecular and Surface Forces*, Revised 3rd edition. Jacob N. Israelachvili, 2011.
- *Solid State Physics: Essential Concepts*. David W. Snoke, 2008.

Students who achieve a score of 70 or above on three of the completed questions and an overall average of 75 or above will pass outright. Students who do not achieve this on their first taking of the written exam will have one more chance to take the written exam the next time the department offers it.

Students who do not achieve an outright passing score on the written may be offered a supplemental oral exam at the discretion of the faculty of the department. A committee of three MSE faculty members will administer the supplemental oral exam within a week of the written exam results. The results of the supplemental oral will be combined with the results of the written to determine pass or no pass. Students who avail themselves of the supplemental oral do not forfeit their right to a second written exam.

Thesis Proposal Evaluation

The Thesis Proposal Evaluation tests the more specific knowledge of the PhD candidate concerning the science underlying the proposed research and 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 document should be prepared by the candidate and be given to each member of the student's Dissertation Advisory Committee (including the non-departmental member) during the semester immediately following the successful completion of the PhD Comprehensive Exam. It should include a literature search, analysis of the research problem, suggested research procedures, and the general results to be expected. The

student's Dissertation Advisory Committee will examine the document for this purpose.

The oral part of the Thesis Proposal Evaluation lasts 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.

PhD Program of Study (Course Requirements)

A PhD 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 PhD program is 5 years, starting with the first semester of EMSE 701 registration.

The minimum course requirement for a PhD degree is 12 courses (36 credit hours) beyond the BS level, out of which at least 6 courses (18 credit hours) must be taken at Case Western Reserve University. Of these 12 courses, 4 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 a MS degree from another discipline, additional courses may be required as decided by the department. A GPA (grade point average) of 3.0 is required.

MSE Core Sequence: The Materials Science and Engineering core sequence (EMSE 503 Structure of Materials, EMSE 504 Thermodynamics of Solids, and EMSE 505 Phase Transformation, Kinetics, and Microstructure) is a required part of the Program of Study for all PhD students. Transfer credit for comparable graduate courses taken at another institution will be allowed on a case-by-case basis. Students may find it helpful to complete the core sequence prior to taking the PhD comprehensive exam.

Breadth Requirement: A broad knowledge of the field of Materials Science and Engineering includes a minimum level of understanding of the following 4 areas:

1. Structural Materials
2. Microcharacterization
3. Functional Materials
4. Processing

The Breadth Requirement for the PhD can be fulfilled by taking a total of 4 courses (12 credit hours); these 4 courses must include at least one course from areas 1, 2, 3, and 4. The department website (<http://engineering.case.edu/emse/node/19>) contains the current list of approved courses for each of these areas.

Basic Science Requirements: A minimum depth in Basic Science of 2 courses (6 credit hours) is required for a PhD 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 website (<http://engineering.case.edu/emse/node/19>) contains the 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 PhD requirements, will be discussed and approved at the time of the Thesis Proposal Evaluation. This form and the associated Supplementary Information form must be approved by the student's Dissertation Committee (excluding the non-departmental member) and

the Chairman of the Department and submitted to the Dean of Graduate Studies within one semester of passing the General Exam.

Upon successful completion of all requirements and research, the PhD candidate must submit a written dissertation as evidence for his/her ability to conduct independent research at an advanced level. The PhD candidate must pass a final oral exam in defense of the dissertation. The Dissertation Committee must consist of at least 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 unbound copies of the final approved version of the thesis for the university, and two bound copies of the thesis, one for the department and one for the student's faculty advisor.

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 deformation processing as well as mechanical 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, manufacturing of laminated materials, metals casting, crystal growth, thin film deposition, metallic glasses, deformation processing of metals.

Environmental Effects

Durability and lifetime extension of materials for solar energy. 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 microscopy, and surface spectroscopies.

Electronic, Magnetic, and Optical Materials

Materials for energy technologies such as photovoltaics, fuel cells, supercapacitors, and wind turbines; processing, properties, and characterization of magnetic materials; ferroelectric and piezoelectric ceramics.

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 furnaces 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, and 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.

Advanced Manufacturing and Mechanical Reliability Center (AMMRC)

The Advanced Manufacturing and Mechanical Reliability Center (AMMRC) 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 temperatures up to 300°C room temperature while a gas (i.e. Ar) based apparatus is used at room temperature.

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. Data 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 AMMRC 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. In addition, an Instron Model 1331 20 kip Servo-hydraulic machine are available for both quasi-static and cyclic testing.

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 Tester: 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.

The Swagelok Center for Surface Analysis of Materials (SCSAM)

The Swagelok Center for Surface Analysis of Materials (SCSAM) is a multi-user facility providing cutting-edge major instrumentation for micro

characterization of materials. SCSAM's instruments encompass a wide and complementary range of characterization techniques, which provide a comprehensive resource for high-resolution imaging, diffractometry, and spatially-resolved compositional analysis.

Current capabilities for SEM (scanning electron microscopy) include four scanning electron microscopes, three of which are equipped for FIB (focused ion beam) micromachining, XEDS (X-ray energy-dispersive spectrometry), and acquisition of EBSP (electron backscattering patterns). Instruments for TEM (transmission electron microscopy) include a 300 kV high-resolution and a 200 kV analytical instrument, both equipped with fields-emission guns and imaging energy filters. Both instruments are capable of XEDS and EELS (electron energy-loss spectrometry). SCSAM's SPM (scanning probe microscopy) capabilities include a UHV (ultra-high vacuum) variable-temperature atomic-resolution system for STM (scanning tunneling microscopy), STS (scanning tunneling spectroscopy), and all models of AFM (atomic-force microscopy), as well as a standard instrument for AFM, which can optionally be operated with a scanning nanoindenter. A stand-alone automated nanoindenter is available as well. SCSAM also operates a laser scanning confocal optical microscope, dedicated to imaging inorganic materials and capable of performing Raman microscopy. For XRD (X-ray diffractometry), SCSAM provides 3 diffractometers capable of a variety of techniques. SCSAM's surface analysis suite of instruments includes an instrument for ToF-SIMS (time-of-flight secondary-ion mass spectrometry), a SAM (scanning Auger microprobe) for spatially resolved AES (Auger electron spectrometry), and an instrument for XPS (X-ray photoelectron spectrometry, also known as ESCA, electron spectrometry for chemical analysis), that accomplishes high spatial resolution by operating with a focused X-ray beam.

SCSAM is administered directly by the CSE (Case School of Engineering) and is central to much of the research carried out by CSE's seven departments. However, the facility is also extensively used by the CAS (College of Arts and Sciences) Departments of Physics, Chemistry, Biology, and Earth, Environmental, and Planetary Sciences, as well as many departments within the School of Medicine and the School of Dental Medicine. In addition to CWRU clients, many external institutions utilize SCSAM's facilities, including NASA Glenn Research Center, the Cleveland Clinic, and numerous Ohio universities. More than 250 users utilize the facility in any given year.

SCSAM's instruments are housed in a centralized area, allowing users convenient access to state-of-the-art tools for their research.

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 \$4,000,000.

- The FEI Tecnai F30 300 kV field-emission gun energy-filtering high-resolution analytical scanning transmission electron microscope has a point resolution below 0.20 nm and an information resolution limit better than 0.14 nm. The instrument is equipped with an EDAX system with a high-energy resolution Si-Li detector for XEDS (X-ray energy-dispersive spectroscopy), a HAADF (high-angle annular dark-field) detector for STEM (scanning transmission electron microscopy), and a Gatan GIF 2002 imaging energy filter including a 2 k-by-2 k pixel slow-scan CCD camera. The GIF in conjunction with the field-

emission gun enable EELS (electron energy-loss spectrometry) with an energy resolution down to below 1 eV.

- The second instrument is a Zeiss LIBRA 200FE, with an accelerating voltage of 200 kV. It is the first Zeiss instrument that combines the versatility of a new, aberration-corrected in-column OMEGA energy filter with the advantages of a field-emission gun and Köhler illumination. The OMEGA filter provides fully integrated energy-filtered imaging and spectroscopy capabilities for comprehensive and complementary studies of materials. The OMEGA filter is pre-aligned and provides ease of operation in EFTEM (energy-filtering TEM), EELS (electron energy-loss spectrometry), HRTEM (high-resolution TEM), STEM (scanning TEM), and selected-area and convergent-beam electron diffraction work. Moreover, since this new filter is corrected for 2nd order aberrations, it provides large isochromatic sample viewing areas and diffraction angle acceptance at sub-eV energy resolution. Excellent instrument performance further results from an advanced 300 mm column concept and a newly developed control electronics for sub-ppm stability. The instrument has been retrofitted with a high-resolution pole piece for superior spatial resolution in still imaging and STEM.

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 the following:

- High-resolution TEM. This technique enables imaging the projected atomistic structure of extended crystal defects, such as heterophase interfaces, grain boundaries, or dislocations.
- CBED (convergent-beam electron diffraction). This technique can be used to obtain crystallographic information (space group) and to determine orientation relationships between small (even nanoscopic) crystallites.
- EFTEM (energy-filtering TEM). This denotes a suite of techniques enabled by an imaging energy filter. In particular, the techniques include zero (energy)-loss filtering for improved contrast in images and diffraction patterns and ESI (electron spectroscopic imaging), 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 TEM, in addition to the FIB systems described above, consist of two dimple-grinders, two electropolishing units, two state-of-the-art PIPS (precision ion polishing systems) by Gatan, and a Fischione NanoMill 1040 for highest-quality specimens by post-processing of FIB-prepared foils.

Scanning Electron Microscopy Laboratory

SEM (scanning electron microscopy) provides valuable specimen information by enabling imaging with particularly great depth of field and stereo-imaging with resolutions down to the nanometer range. The topography of nearly any solid surface is possible with SEM. Spectrochemical studies are enabled by XEDS (X-ray energy-dispersive spectrometry) systems capable of detecting elements from boron to uranium. The laboratory houses four instruments:

- The Hitachi S-4500 is a field emission electron microscope with two secondary electron detectors, a backscattered-electron detector, and an infrared chamber scope. In addition, it has a Bruker SDD XEDS system. The microscope is capable of operating at a spatial resolution of 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 dual beam FIB (focused ion beam), the xT Nova Nanolab 200 (FEI). In addition to the focused ion beam, which is used for preparing thin foils suitable for TEM directly out of the specimen surface, this instrument includes a complete and very-high-quality scanning electron microscope. This system has the advantage that the specimen can be observed by (high-resolution) SEM while being milled by the ion beam. Compared to previous FEI FIB systems, the Nova has an improved computer interface and software that enables entirely automated milling. Moreover, the Nova includes a newly designed internal “lift-out-” system for transferring the thin film generated by ion-beam milling onto a special Cu support grid, which can then be loaded into the specimen holder of a TEM. For elemental and crystallographic analysis, the system is equipped with a state-of-the-art Oxford AZtec system with a X-max 50mm² detector and a NORDLYS EBSP camera. EBSD mapping of phase and orientation relies on evaluating EBSP patterns of every scan point.
- The third instrument is an FEI Quanta 200 3D. This is a versatile low-vacuum SEM/FIB for 2D and 3D material characterization and analysis. It features three imaging modes: high-vacuum, low-vacuum, and ESEM, and can accommodate a wide range of samples. The instrument is equipped with a field-emission Ga ion source and a thermal electron emitter. The enabling technologies, integrated onto a single platform, further include high-volume milling capabilities, ESEM differential pumping variable pressure vacuum system (oil-free), gaseous secondary and backscattered electron detectors for imaging and analysis in a gaseous chamber environment, gas chemistry technology for enhanced milling rates, high-precision specimen goniometer with 50 mm travel along the x and y axes, automation serving unattended sectioning with full access to e-beam, i-beam, patterning, and gas chemistry functionality.
- The fourth instrument, a Helios NanoLab™ 650, features FEI's most recent advances in field-emission SEM and FIB (focused ion beam) technologies and their combined use. It is designed to access a “new world” of extremely high-resolution 2D and 3D characterization, 3D nano-prototyping, and higher quality TEM sample preparation. The Helios's capability of robust and precise FIB slicing, combined with a high-precision piezo stage (150 x 150 mm²), superb SEM performance, and advanced software allow unattended sample preparation or 3D characterization and analysis.

The outstanding imaging capabilities of the Helios NanoLab begin with its Elstar™ FESEM. Thanks to its integrated monochromator (UC) and beam deceleration, it delivers sub-nanometer resolution across the whole 1-30 kV range. The Elstar features other unique technologies such as constant power lenses for higher thermal stability and electrostatic scanning for higher deflection linearity and speed. Its through-the-lens detector, set for highest collection efficiency of SE (secondary electrons) and on-axis BSE (backscattered electrons), is complemented by FEI's latest advanced detection suite including three novel detectors: two multi-segment solid state detectors: CBS detector for backscattered electron imaging able to detect low kV BSE, a scanning transmission electron mode detector able to record simultaneously BF, DF and HAADF images, and a third dedicated to FIB-SE and -SI (secondary ion) imaging. The Helios NanoLab has the latest electron- and focused ion beam technology: an Elstar™ field-emission gun electron column with integrated monochromator (UC) and beam deceleration and a versatile Tomahawk focused ion beam column, featuring excellent FIB imaging and outstanding low-kV operation down to 500 V and up to 65 nA beam

current. The Helios system is equipped with a state-of-the-art XEDS X-Max 80 mm² silicon drift detector (SDD) system by Oxford with an energy resolution of 125 eV at Mn K α (5.899 keV) at full width at half maximum. The extremely large active area significantly increases the collection solid angle. This results in a detector that performs measurements either more quickly at conditions at which traditional systems would be used or at higher energy resolution. The increased sensitivity allows the system to operate at much lower beam currents. This reduces the risk of sample damage.

Surface Science Laboratories

SCSAM's tools for surface science include three instruments for surface analysis in UHV (ultra-high vacuum), two scanning probe systems, and a dedicated nanoindenter, all detailed below:

- A PHI 680 scanning Auger microprobe. This system consists of a field-emission scanning electron microscope with a Schottky emission cathode, a secondary electron detector, and an axial cylindrical mirror analyzer with a multi-channel detector to collect Auger electrons produced during electron imaging. Very small spot sizes can be realized with this instrument, down to 7 nm. This is useful for high-resolution imaging and for Auger data acquisition using low beam currents. Inert gas sputtering (using a PHI 06-350 ion gun) is used to clean surface contamination from samples and to remove material from a small area on the surface for depth profiling. Several modes of operation are available to the user, including survey, line, profile, and elemental mapping. Capable of multi-point analysis, the instrument is a powerful tool for routine failure analysis and quality control of inorganic samples. An additional device permits *in situ* fracture of samples, at liquid nitrogen temperature if necessary.
- A PHI VersaProbe XPS Microprobe. Based on XPS (X-ray photoelectron spectrometry, also known as ESCA – electron spectrometry for chemical analysis), this is a multi-technique surface analysis instrument based on PHI's highly developed scanning X-ray microprobe technology. The most important advantage of this instrument is that the VersaProbe can produce a focused, highly monochromatic X-ray beam that can be scanned over the specimen surface. In this instrument, a point source of X-rays is created by focusing an electron beam onto an Al anode. A monochromator, consisting of an ellipsoid-shaped crystal, collects X-rays from the point source and focuses them on the surface of the specimen. The focused X-ray beam can be scanned across the specimen surface by correspondingly scanning the electron beam across the surface of aluminum anode. A major advantage of this design is that most of the photoelectrons generated by the focused X-ray beam are actually collected by the electron energy analyzer, whereas in the conventional design, most of the photoelectrons are lost. With the VersaProbe, the spot size can be varied between less than 10 μm diameter (for highest spatial resolution) to 100 μm (for highest sensitivity).
- A TRIFT V nanoTOF made by PHI. This is a time-of-flight secondary-ion mass spectrometer. This instrument is from the latest generation of PHI's surface analysis line of ToF-SIMS instruments, utilizing a newly developed, high-quality "TRIFT" analyzer. It is equipped with a Au-, a C60-, and an Ar gun. An innovative new sample handling platform enables analysis of samples with complex geometries. In addition, the system has state-of-the-art charge compensation and ion gun performance.

ToF-SIMS (time-of-flight secondary-ion mass spectrometry) provides sub-micrometer 3D (!) elemental mapping. It can also be used to image the topography of solid surfaces. Different from D-SIMS

("dynamic" SIMS), ToF-SIMS enables analyzing the outermost one or two mono-layers of a sample while basically preserving molecular integrity. While D-SIMS provides primarily elemental information, ToF-SIMS surface analysis yields chemical and molecular information. ToF-SIMS is ideal for both organic and inorganic materials and can be used to characterize both insulating and conductive samples. With detection limits in the ppm to ppb range, shallow depth profiling capabilities and automated analysis, the nanoTOF can be used to study surface contamination, trace impurities, films, delamination failures etc. It is also a valuable tool to investigate surface modification chemistry and catalyst surface composition.

- A Dimension 3100 (Veeco Digital Instruments). This is a state-of-the-art multi-mode scanning probe microscope (SPM), equipped with a NanoScope IIIa controller and Quadrex signal processor for 16-bit resolution on all 3 axes. The tool works under atmospheric pressure at room temperature and can work in air and in liquids, so that a full range of materials (metals, insulators, ceramics, polymers, and biological specimens) can be investigated with minimal sample preparation. It can accept samples up to 20 cm in diameter, with a height limitation of < 1.5 cm and a surface roughness limitation of < 5.5 mm. The instrument is equipped with an in-line optical zoom microscope with color CCD camera, with a maximum magnification of 800X for precise placement of the SPM probe onto the sample. The Dimension 3100 can operate in numerous imaging modes, the primary operation being atomic force microscopy (AFM) in contact mode, tapping mode, and phase imaging mode. Other data collection techniques include conductive-AFM to characterize conductivity variations, magnetic force microscopy, which uses a ferromagnetic-coated tip to probe magnetic fields, and force-distance measurements, which are performed to study attractive and repulsive forces on a tip as it approaches and retracts from the sample surface. Further, the Dimension 3100 SPM has been upgraded by a "TriboScope," an attachment for nanomechanical testing, made by Hysitron. The TriboScope is a quantitative, depth-sensing nanoindentation and nanoscratch system that interfaces with the SPM. This attachment enables quantitative characterization of mechanical properties (hardness, scratch resistance, wear resistance) on the nanometer length scale and *in situ* AFM imaging of the surface topography before and after mechanical testing. The capability of *in situ* imaging allows the user to choose the exact area, with sub-nm precision, for each nanoindentation/nanoscratch investigation, and to fully characterize the local specimen surface.
- An RKH 7500 UHV VT. This system includes a variable-temperature ultra-high vacuum scanning probe microscope, made by RHK Technologies. This instrument is part of a complete UHV (ultra-high vacuum) system, which includes a separately pumped specimen preparation chamber and a load-lock chamber in addition to the actual SPM (scanning probe microscopy) chamber. The base pressure of the system is specified to $2 \cdot 10^{-12}$ Pa. In the preparation chamber, an electron gun combined with a hemispherical electron energy analyzer is attached to enable chemical analysis of the specimen surface via AES (Auger electron spectroscopy). A specimen manipulator installed on the vertical axis of the chamber allows precise positioning of the specimen in front of the electron energy analyzer. The manipulator can be connected to a cryostat via a differentially-pumped rotary stage, permitting cooling the specimen down to 25 K. By resistive or electron-beam heating, it will also be possible to heat the specimen up to temperatures of 1500 K.

To be able to clean the specimen surface, the system includes an Ar sputter gun. Evaporators installed at ports in the lower half of the chamber enable the deposition of metals onto the specimen surface. A gas dosing system facilitates gas adsorption experiments without backfilling the entire chamber or opening the main chamber to change gases. A mass spectrometer constantly detects and analyzes residual gas in the chamber. Finally, the preparation chamber includes a port large enough for a retractable reverse view LEED (low-energy electron diffraction) system for studying the surface structure of the specimen.

Using a magnetic transfer arm, the specimen can be moved from the preparation chamber into the actual SPM chamber. This chamber houses a cantilever atomic force microscope combined with a scanning tunneling microscope, suitable to image the surface structure of conducting as well as non-conducting materials. Both instruments are capable of atomic-resolution imaging. The scanning tunneling microscope also permits probing the local work function and the local density of states in the specimen surface by STS (scanning tunneling spectrometry). All modes of SPM will work over a very broad range of specimen temperatures: 25 to 750 K. The SPM chamber accepts thermal evaporators, a sputter gun and a gas dosing system that can perform their functions while the sample is actively being studied by any of the available scanning probe techniques.

- An Agilent Nano Indenter G200. This is a very accurate, flexible, user-friendly instrument for nanomechanical testing. Electromagnetic actuation allows unparalleled dynamic range in force and displacement and measurement of deformation over six orders of magnitude (from nanometers to millimeters). Potential applications include a wide scope of materials, e.g. semiconductors, films, MEMs (wafer applications), coatings and DLC films, composite materials, fibers, polymers, metals, ceramics, and biomaterials.

X-Ray Diffractometry Laboratory

The XRD (X-ray diffractometry) laboratory contains equipment for studying the atomistic structures of mainly crystalline inorganic materials. Three instruments are available:

- A Scintag X1 diffractometer system. This includes a theta/theta wide-angle goniometer, a 4.0 kW X-ray generator with Cu tube, a third axis stress attachment, a thermoelectrically cooled Peltier Ge detector, a film analysis system, a dedicated PC for data acquisition, and a turbomolecular-pump evacuated furnace attachment permitting sample temperatures up to 1700 K.
- A Bruker Discover D8 X-ray diffractometer. This instrument has a monochromated Co X-ray source configured in point-focus mode. X-ray collimators are available for spot sizes from 200 μm to 800 μm , with 500 μm typical. The instrument houses a four-circle Huber goniometer equipped with an xyz stage and a laser video system to allow precision alignment of samples. A 2D Hi-Star detector allows a wide range of XRD techniques to be executed in short times. The 2D detector has a high sensitivity and is very useful for detecting phases with volume fraction so small that they might be missed by a conventional (0D) diffractometer. In addition, the 2D detector allows rapid measurements of stress and texture in a wide variety of materials

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, and an Infra-red microscope.

Magnetometry Laboratory

The Magnetometry Laboratory has facilities used to investigate the magnetic properties of materials. This laboratory has two instruments:

- A Lake Shore Cryotronics Model 7410 Vibrating Sample Magnetometer for measurement of hysteresis loops (at constant temperature) and thermomagnetic measurements (at constant magnetic field). The maximum applied field at room temperature (without furnace in place) is 3.1 Tesla. For high temperature measurements, the maximum applied field is 2.5 Tesla over the temperature range from room temperature to 1000°C.
- A home-built magnetostriction measurement system has been designed and built to measure the shape change of magnetic materials under applied magnetic fields. Better than 1 ppm sensitivity is possible by this strain gage technique. An applied field of ~0.2 Tesla is used to saturate samples.

Fuel Cell Testing Laboratory

Facilities (located in the A. W. Smith Building) for testing of solid oxide fuel cells include:

- 2 test stands for 4" cells and small stacks (Fuel Cell Technologies); test temperatures to 1000°C; professional turnkey LabView interface for system control and data acquisition
- 2 test stands for 1" cells; test temperatures to 1000°C; LabView interface for complete system control and data acquisition; Omega mass flow controllers; Keithley and Amrel electronics; AutoLab Electrochemical Analyzer for I-V, galvanostatic or amperometric testing and AC impedance spectroscopy
- All test stands contained in dedicated enclosures rated for use with hydrogen, hydrogen sulfide, and carbon monoxide with ventilation system, leak detection, tank pressure monitors, alarm system
- Dedicated furnaces and ovens for preparing cells for testing

The Solar-Durability and Lifetime Extension (S-DLE) Center

The *Solar-Durability and Lifetime Extension (S-DLE) Center* located in CWRU's White Hall, along with its S-DLE (Sun Farm) on CWRU's West Quad is focused on long lifetime, environmentally exposed materials technologies such as photovoltaics, energy efficient lighting and building envelope applications. It is a Wright Projects center, funded by the Ohio Third Frontier commission. The center was founded to develop real-time and accelerated protocols for exposure to solar radiation and related environmental stressors to enable evaluation of the environmental durability and lifetime of materials, components, and products. Post-exposure optical and thermo-mechanical measurements are used to develop quantitative mechanistic models of degradation processes in

the bulk of the device materials and at the inherent interfaces between dissimilar materials. The *S-DLE Center's* capabilities include:

- Solar exposures: 2-axis solar trackers with multi-sun concentrators, and power degradation monitoring
- Solar simulators for 1 to 1000X exposures
- Multi-factor environmental test chambers with temperature, humidity, freeze/thaw and cycling
- A full suite of optical, interfacial, thermo-mechanical and electrical evaluations of materials, components and systems

The Wind Energy Research and Commercialization (WERC) Center

The WERC Center is a multidisciplinary center for use by students, faculty, and industry providing instrumentation for wind resource characterization and research platforms in operating wind turbines. The WERC Center was established in 2010 with funding from the Ohio Department of Development Third Frontier Wright Project and the Department of Energy. Additional support was provided by the following inaugural industrial partners: Cleveland Electric Laboratories, The Lubrizol Corporation, Parker Hannifin Corporation, Azure Energy LLC, Rockwell Automation, Inc., Swiger Coil Systems LLC, and Wm. Sopko & Sons Co.

The instruments in the WERC Center include:

- A continuous scan ZephIR LiDAR, manufactured by Natural Power. This instrument measures horizontal and vertical wind velocity along with wind direction at 1 Hz frequency at five user set heights up to 200 m.
- Five meteorological measurement systems: 3 on campus; 1 with the off campus wind turbines; and one at the City of Cleveland's water intake crib located 3.5 miles offshore in Lake Erie.
- An ice thickness sensor that is deployed at the bottom of Lake Erie each fall and retrieved in the spring.
- A NorthWind 100 wind turbine manufactured by Northern Power Systems in Barre, VT USA. This 100kW community scale wind turbine has a direct drive generator with full power inverters, stall control blades with a 21 m rotor diameter, and a 37 m hub height. This wind turbine is located on campus just east of Van Horn field and began operation in November, 2010.
- A Vestas V-27 wind turbine originally manufactured by Vestas in Denmark. This 225kW medium scale wind turbine has a gearbox drive generator, pitch controlled blades with a 27 m rotor diameter, and a 30 m hub height. In addition it has a 50kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in March, 2012.
- A Nordex N-54 wind turbine originally manufactured by Nordex in Germany. This 1.0MW utility scale wind turbine has a gearbox drive generator, stall control blades with a 54 m rotor diameter, and a 70 m hub height. In addition it has a 200kW generator for low wind generation. This wind turbine is located at an industrial site in Euclid, OH about 15 minutes from campus and began operation in October, 2012.

Faculty

James D. McGuffin-Cawley, PhD
(Case Western Reserve University)
Chair; Arthur S. Holden Professor of Engineering
Powder processing of ceramics; manufacturing and materials; additive manufacturing and rapid prototyping; aggregation phenomena; defects, diffusion, and solid state reactions; materials for optical devices.

William A. "Bud" Baeslack III, PhD
(Rensselaer Polytechnic Institute)
Provost and Executive Vice President
Welding, joining of materials, and titanium and aluminum metallurgy.

Jennifer W. Carter, PhD
(The Ohio State University)
Assistant Professor
Processing-structure-property relationships of crystalline and amorphous materials; development and implementation of novel multi-scale material characterization methods for correlating unique local microstructural features with particular mechanical and environmental responses in a variety of material systems.

Mark R. DeGuire, PhD
(Massachusetts Institute of Technology)
Associate Professor
Synthesis and properties of ceramics in bulk and thin-film form, including fuel cell materials, gas sensors, coatings for biomedical applications, photovoltaics, and ferrites. Testing and microstructural characterization of materials for alternative energy applications. High-temperature phase equilibria. Defect chemistry.

Frank Ernst, PhD
(University of Göttingen)
Leonard Case Jr. Professor of Engineering
Microstructure and microcharacterizations; 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.

Roger H. French, PhD
(Massachusetts Institute of Technology)
F. Alex Nason Professor of Materials Science
Optical materials science, including optical properties, electronic structure, and radiation durability of optical materials, polymers, ceramics and liquids using vacuum ultraviolet and optical spectroscopies and spectroscopic ellipsometry. Lifetime and degradation science of photovoltaic materials, components and systems including solar radiation durability and degradation mechanisms and rates. Quantum electrodynamics and van der Waals – London dispersion interactions applied to wetting, and long range interactions for manipulation of nanoscale objects such as carbon nanotubes and biomolecular materials.

Timothy Peshek, PhD
(Case Western Reserve University)
Assistant Research Professor
Developing new opportunities in power electronics and electronic devices.

Arthur H. Heuer, PhD, DSc
(University of Leeds, England)

Distinguished University Professor; Kyocera Professor of Ceramics; Director, Swagelok Center for Surface Analysis of Materials
Interstitial hardening and improved corrosion resistance of stainless steels and nickel-base alloys; oxidation and hot corrosion of nickel-base and iron-base alloys; improved corrosion resistance of aluminum base alloys; solid oxide fuel cells; high resolution and analytical electron microscopy; 3D reconstruction of soft tissue for life science applications; oxygen and aluminum lattice and grain boundary diffusion in aluminum oxide; dislocations and plastic deformation of aluminum oxide; quantum mechanics of point defects, dislocations, and grain boundaries of aluminum oxide; and electronic structure of aluminum oxide.

Harold Kahn, PhD
(Massachusetts Institute of Technology)
Research Associate Professor

Materials reliability in microsystems technology and microelectromechanical systems; surface engineering of steels and alloys; mechanical testing of biological nanofibrils; microfluidic and micro-optical devices.

Peter Lagerlof, PhD
(Case Western Reserve University)
Associate Professor

Mechanical properties of ceramics and metals. Of particular interest is to understand how low temperature deformation twinning is related to plastic deformation by dislocation slip at elevated temperatures. Deformation twinning models for both basal and rhombohedral twinning in sapphire, which are properly related to dislocation slip at elevated temperatures, have been established. The basal twinning model has been confirmed experimentally using TEM techniques. Current research involves studies on how to generalize this twinning model to other materials systems; i.e., metals, intermetallic compounds and other ceramics.

John J. Lewandowski, PhD
(Carnegie Mellon University)

Arthur P. Armington Professor of Engineering; Director, The Advanced Manufacturing and Mechanical Reliability Center (AMMRC)
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, PhD
(Massachusetts Institute of Technology)
Associate Professor; Director, Wind Energy Research and Commercialization (WERC) Center

Materials for use in wind turbines; wind resource measurements onshore and offshore; materials interactions with ice; bulk crystal growth processing; process engineering in manufacturing; heat, mass, and momentum transport.

P. Pirouz, PhD
(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.

Alp Sehirliogou, PhD
(University of Illinois at Urbana Champaign)
Assistant Professor

High-temperature piezoelectrics for actuators and ultrasonic applications; electro-thermal imaging; multifunctional electro-ceramics.

David Schwam, PhD
(The Technion University)
Research Associate Professor

Gating of advanced aluminum and magnesium alloys, development of die and permanent mold materials, thermal fatigue testing, recycling.

Gerhard E. Welsch, PhD
(Case Western Reserve University)
Professor

Metals and oxides; high temperature properties, mechanical and electrical properties. Materials for capacitive energy storage; metal sponges; high temperature materials, metal-cell composites. Synthesis of materials.

Matthew A. Willard, PhD
(Carnegie Mellon University)

Associate Professor; Director, Case Metals Casting Laboratory
Magnetic materials, including their magnetic properties, microstructure evolution, phase formation, and processing conditions; critical materials and sustainability, especially reducing dependence on rare earths through novel alloy design; rapid solidification processing of materials, with an emphasis on nanostructured and amorphous alloys; soft magnetic materials for power conditioning, conversion, and generation technologies and permanent magnet materials for motor, generator, and actuator applications (especially in energy dense applications and in extreme environments); other magnetic related phenomena, including magnetic shape memory alloys, magnetocaloric effects, magnetic nanoparticles, and multiferroics.

Secondary Faculty

Clemens Burda, PhD
Professor of Chemistry

Walter Lambrecht, PhD
Professor of Physics

Mohan Sankaran, PhD
Professor in Chemical Engineering

Nicole F. Steinmetz, PhD
Assistant Professor of Biomedical Engineering

Russell Wang, DDS
Associate Professor of Dentistry

Xiong (Bill) Yu, PhD, PE
Assistant Professor of Civil Engineering

Adjunct Faculty

Arnon Chait
Adjunct Professor
NASA Glenn Research Center, Brookpark, OH

N.J. Henry Holroyd
Adjunct Professor
Luxfer Gas Cylinders, Riverside, CA

Jennie S. Hwang
Adjunct Professor
H-Technologies Group, Cleveland, OH

Ina Martin, PhD
(Colorado State University)
Adjunct Assistant Professor

Terence Mitchell
Adjunct Professor
Los Alamos National Laboratory, Los Alamos, NM

Badri Narayanan
Adjunct Assistant Professor
Lincoln Electric Co., Euclid, OH

Rudolph Podgornik, PhD
(University of Ljubljana)
Adjunct Professor

Gary Ruff
Adjunct Professor
Ruff Associates, Rochester Hills, MI

Ali Sayir, PhD
(Case Western Reserve University)
Adjunct Professor
Structure/property relationships in ferroelectric and piezoelectric ceramics, in actuators and sensors for engine and energy harvesting applications, thermoelectric energy conversion, high temperature ceramics for hydrogen separation

Courses

EMSE 110. Transitioning Ideas to Reality I - Materials in Service of Industry and Society. 1 Unit.

In order for ideas to impact the lives of individuals and society they must be moved from "blue sky" to that which is manufacturable. Therein lies true creativity - design under constraint. Greater Cleveland is fortunate to have a diverse set of industries that serve medical, aerospace, electric, and advanced-materials technologies. This course involves trips to an array of work sites of leading companies to witness first-hand the processes and products, and to interact directly with practitioners. Occasional in-class speakers with demonstrations will be used when it is not logistically reasonable to visit off-site.

EMSE 120. Transitioning Ideas to Reality II - Manufacturing Laboratory. 2 Units.

This course complements EMSE 110. In that class students witness a diverse array of processing on-site in industry. In this class students work in teams and as individuals within processing laboratories working with an array of "real materials" to explore the potential of casting, machining, and deformation processes to produce real parts and/or components. An introduction to CAD as a means of communication is provided. The bulk of the term is spent in labs doing hands-on work. Planned work is carried out to demonstrate techniques and potential. Students have the opportunity to work independently or in teams to produce articles as varied as jewelry, electronics, transportation vehicles, or novel components or devices of the students' choosing.

EMSE 125. Freshman Research in Materials Science and Engineering. 1 Unit.

Freshman students conduct independent research in the area of material science and engineering, working closely with graduate student(s) and/or postdoctoral fellow(s), and supervised by an EMSE faculty member. An average of 5-6 hr/wk in the laboratory, periodic updates, and an end of semester report is required. Prereq: Limited to freshman, with permission of instructor.

EMSE 146. Principles and Applications of Materials Chemistry. 4 Units.

An introduction to the role that fundamental chemical principles play in the structure, processing, properties, and applications of materials. The origins and types of primary and secondary chemical bonds, and how they determine mechanical, electrical, thermal, optical, and magnetic properties of metals, ceramics, polymers and electronic materials. Equilibrium thermodynamics applied to the synthesis of materials and their reactions with the environment. Examples drawn from current breakthroughs utilized in high-technology applications. Active learning techniques, demonstrations, guest lectures, and a limited number of off-campus site visits will be utilized throughout the course. Intended for students seeking a degree in a materials-intensive field or a minor track that is materials-intensive. Prereq: (MATH 121 and CHEM 111) or (MATH 121 and CHEM 105 and CHEM 106). Coreq: PHYS 121 or PHYS 123.

EMSE 220. Materials Laboratory I. 2 Units.

Experiments designed to introduce processing, microstructure and property relationships of metal alloys and ceramics. Solidification of a binary alloy and metallography by optical and scanning electron microscopy. Synthesis of ceramics powders, thermal analysis using thermogravimetric analysis and differential thermal analysis, powder consolidation. Kinetics of high-temperature sintering, grain growth, and metal oxidation. Statistical analysis of experimental results. Recommended preparation or recommended co-requisite: EMSE 276.

EMSE 228. Mathematical Methods for Materials Science and Engineering. 3 Units.

Problems in materials science and engineering drawn from thermodynamics, material property measurements, heat transfer, mass transfer, and failure analysis. Students will develop a fundamental understanding of the basis for solving these problems including understanding the constituent equations, solution methods, and analysis and presentation of results. Students will then solve these problems using current computational tools employed by practicing materials engineers and scientists. Advantages and disadvantages of techniques using spreadsheets, programming languages, and specialized programs. Recommended preparation or recommended co-requisite: MATH 224 or MATH 228. Prereq: EMSE 276 and (ENGR 131 or EECS 132) and (PHYS 121 or PHYS 123) and (MATH 122 or MATH 124).

EMSE 276. Materials Properties and Design. 3 Units.

Relation of crystal structure, microstructure, and chemical composition to the properties of materials. The role of materials processing in controlling structure so as to obtain desired properties, using examples from metals, ceramics, semiconductors, and polymers. Design content includes exercises in materials selection, and in design of materials to meet specified performance requirements. Prereq: MATH 121 and (ENGR 145 or EMSE 146). Prereq or Coreq: PHYS 122 or PHYS 124.

EMSE 301. Fundamentals of Materials Processing. 3 Units.

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. Recommended preparation: EMSE 201 and EMSE 202 and EMSE 203.

EMSE 307. Foundry Metallurgy. 3 Units.

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. Recommended preparation: EMSE 202 and EMSE 203 and ENGR 225.

EMSE 310. Applications of Diffraction Principles. 1 Unit.

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. Recommended preparation: EMSE 312 or consent of instructor.

EMSE 312. Diffraction Principles. 3 Units.

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. Recommended preparation: (EMSE 201 or EMSE 276) and MATH 224.

EMSE 313. Engineering Applications of Materials. 3 Units.

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. Recommended preparation: EMSE 202 and ENGR 200.

EMSE 319. Processing and Manufacturing of Materials. 3 Units.

Introduction to processing technologies by which materials are manufactured into engineering components. Discussion of how processing methods are dependent on desired composition, structure, microstructure, and defects, and how processing affects material performance. Emphasis will be placed on processes and treatments to achieve or improve chemical, mechanical, physical performance and/or aesthetics, including: casting, welding, forging, cold-forming, powder processing of metals and ceramics, and polymer and composite processing. Coverage of statistics and computational tools relevant to materials manufacturing. Prereq: EMSE 276 or EMSE 201.

EMSE 320. Materials Laboratory II. 1 Unit.

Measurement of thermophysical properties of materials emphasizing thermal and electrical properties of materials. Laboratory teams are selected for all experiments. Statistical analysis of experimental results also emphasized. Recommended preparation or corequisite: EMSE 276.

EMSE 325. Undergraduate Research in Materials Science and Engineering. 1 - 3 Unit.

Undergraduate laboratory research in materials science and engineering. Students will undertake an independent research project alongside graduate student(s) and/or postdoctoral fellow(s), and will be supervised by an EMSE faculty member. Written and oral reports will be given on a regular basis, and an end of semester report is required. The course can be repeated up to four (4) times for a total of six (6) credit hours. Prereq: Sophomore or Junior standing and consent of instructor.

EMSE 327. Thermodynamic Stability and Rate Processes. 3 Units.

An introduction to thermodynamics of materials as applied to metals, ceramics, polymers and optical/radiant heat transfer for photovoltaics. The laws of thermodynamics are introduced and the general approaches used in the thermodynamic method are presented. Systems studied span phase stability and oxidation in metals and oxides; nitride ceramics and semiconductors; polymerization, crystallization and block copolymer domain formation; and the thermodynamics of systems such as for solar power collection and conversion. Recommended preparation: EMSE 228 and ENGR 225 or equivalent. Prereq: EMSE 276 or EMSE 201.

EMSE 328. Meso-scale Science Including Nanotechnology. 3 Units.

Mesoscale science focuses on addressing the frontiers of complex systems, between quantum and classical, nano and macro, and across the four dimensions of space and time. Nanoscience continues to advance, and multi-scale approaches are used to bridge orders of magnitude in length scales. This course will explore tools that are needed to bridge different length scales, including crystallography (crystal symmetries, point groups, crystal systems and space groups), crystal chemistry, characterization of microstructures (including grains, inclusions, second phases, texture, and voids), diffraction principles and their application in characterizing materials at differing length scales (nano, micro, meso, macro), device characterization methods, and fabrication technologies and processes. Offered as: EMSE 328 and EMSE 428. Prereq: (MATH 223 or MATH 227) and (EMSE 276 or EMSE 201).

EMSE 330. Materials Laboratory III. 2 Units.

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. Statistical analysis of experimental results. Recommended preparation: EMSE 276. Recommended preparation or co-requisites: EMSE 319 and EMSE 327.

EMSE 335. Strategic Metals and Materials for the 21st Century. 3 Units.

This course seeks to create an understanding of the role of mineral-based materials in the modern economy focusing on how such knowledge can and should be used in making strategic choices in an engineering context. The history of the role of materials in emerging technologies from a historical perspective will be briefly explored. The current literature will be used to demonstrate the connectedness of materials availability and the development and sustainability of engineering advances with examples of applications exploiting structural, electronic, optical, magnetic, and energy conversion properties. Processing will be comprehensively reviewed from source through refinement through processing including property development through application of: titanium, beryllium, molybdenum, cobalt, vanadium, manganese, tantalum, rhenium, and rare earth group metals. The concept of strategic recycling, including design for recycling and waste stream management will be considered. Offered as EMSE 335 and EMSE 435. Prereq: Senior standing or graduate student.

EMSE 343. Materials for Electronics and Photonics. 3 Units.

This course covers the basics of planar processing, which is the foundation of producing semiconductor chips and photonic devices, and the way these devices are incorporated into electronics and display technologies. Basic characteristics of semiconductors and optoelectronic devices; and how advances in these technologies arise from, and drive, advances in materials and device architecture. Offered as: EMSE 343 and EMSE 443. Prereq: (PHYS 122 or PHYS 124) and (EMSE 276 or EMSE 201).

EMSE 345. Materials for Biological and Medical Technology. 3 Units.

A survey of natural biomaterials and synthetic biomedical materials from the perspective of materials science and engineering, focusing on how processing/synthesis, structure, and properties determine materials performance. Structure and properties of bones and teeth, soft tissue, and cartilage. Introduction to properties and applications of materials for medical technologies, such as orthopedic implants, sensors, transducers, and materials for biomedical imaging and drug delivery. Selected case studies. Biomimetics as a design strategy for synthetic materials. Prereq: ENGR 200 and (ENGR 145 or EMSE 146).

EMSE 349. Materials for Energy and Sustainability. 3 Units.

Levels and categories of energy usage in the U.S. and the world. Availability of raw materials, including strategic materials; factors affecting global reserves and annual world production. Design options to circumvent limitations of supplies. Resource demand (energy and water) of materials production, fabrication, and recycling. Roles of engineered materials in renewable or advanced energy technologies: photovoltaics, fuel cells, wind, batteries, capacitors, thermoelectrics. Energy harvesting. Energy return on energy invested. Semester projects will enable students to explore related topics (e.g. geothermal; biomass; solar thermal; advances in energy-efficient manufacturing) in greater depth. Prereq: ENGR 225 and (ENGR 145 or EMSE 146) and (PHYS 122 or PHYS 124) or requisites not met permission.

EMSE 360. Transport Phenomena in Materials Science. 3 Units.

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. Recommended preparation: ENGR 225 and MATH 224 or equivalent.

EMSE 372. Structural Materials by Design. 4 Units.

Materials selection and design of mechanical and structural elements with respect to static failure, elastic stability, residual stresses, stress concentrations, impact, fatigue, creep, and environmental conditions. Mechanical behavior of engineering materials (metals, polymers, ceramics, composites). Influence of ultrastructural and microstructural aspects of materials on mechanical properties. Mechanical test methods. Models of deformation behavior of isotropic and anisotropic materials. Methods to analyze static and fatigue fracture properties. Rational approaches to materials selection for new and existing designs of structures. Failure analysis methods and examples, and the professional ethical responsibility of the engineer. Four mandatory laboratories, with reports. Statistical analysis of experimental results. Recommended Preparation: EMSE 276. Offered as EMAE 372 and EMSE 372. Prereq: ENGR 200.

EMSE 379. Design for Lifetime Performance. 3 Units.

The roles of processing and properties of a material on its performance, cost, maintenance, degradation and end-of-life treatment. Corrosion and oxidation, hydrogen and transformation-induced degradation mechanisms. Defects from prior processing. New defects generated during use/operation, e.g. generated from radiation, stress, heat etc. Accumulation and growth of defects during use/operation; crack nucleation, propagation, failure. Impact, abrasion, wear, corrosion/oxidation/reduction, stress-corrosion, fatigue, fretting, creep. Evaluation of degradation: Non-destructive versus destructive methods, estimation of remaining lifetime. Mitigation of degradation mechanisms. Statistical tools for assessing a material's lifetime performance. Capstone design project. Prereq: EMSE 372 and (EMSE 301 or EMSE 319).

EMSE 396. Special Project or Thesis. 1 - 18 Unit.

Special research projects or undergraduate thesis in selected material areas.

EMSE 398. Senior Project in Materials I. 1 Unit.

Independent Research project. Projects selected from those suggested by faculty; usually entail original research. The EMSE 398 and 399 sequence form an approved SAGES capstone. Counts as SAGES Senior Capstone.

EMSE 399. Senior Project in Materials II. 2 Units.

Independent Research project. Projects selected from those suggested by faculty; usually entail original research. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Recommended preparation: EMSE 398 or concurrent enrollment.. Counts as SAGES Senior Capstone.

EMSE 400T. Graduate Teaching I. 0 Units.

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. Recommended preparation: Ph.D. student in Materials Science and Engineering.

EMSE 401. Transformations in Materials. 3 Units.

Review of solution thermodynamics, surfaces and interfaces, recrystallization, austenite decomposition, the martensite transformation and heat treatment of metals. Recommended preparation: EMSE 202.

EMSE 403. Modern Ceramic Processing. 3 Units.

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. Recommended preparation: EMSE 316 or concurrent enrollment.

EMSE 404. Diffusion Processes in Solids and Melts. 3 Units.

Development of the laws of diffusion and their applications. Carburization and decarburization, oxidation processes. Computer modeling of diffusion processing.

EMSE 405. Dielectric and Electrical Properties of Materials. 3 Units.

I- Fundamentals: (i) Thermodynamic relationships between electrical, mechanical and thermal properties. Boundary conditions of properties and measurements. Primary and secondary effects contributing to the total effects measured. (ii) Defects. Electronic structure of covalently and ionically bonded materials. Ionic compensation as a function of surrounding atmosphere. Kroger-Vink diagrams. (iii) Anisotropy. Representation of properties with tensors and matrices. Representative surfaces of properties. Point groups and symmetry operations. II- Equilibrium properties of nonmetals: Dielectrics, ferroelectrics, pyroelectrics, relaxors, electrocaloric materials and piezoelectrics. Applications. Relationship between microscopic and macroscopic properties. III- Transport Properties: Ceramic conductors, NTCR and PTCR materials, thermoelectrics.

EMSE 406. Optical Materials, Elements and Technologies. 3 Units.

Optical materials, elements and technologies are the focus of this course. Inorganic or organic optical materials are defined by their optical properties, radiation durability under ultraviolet and solar irradiation, and ancillary properties required for robust application. Optical elements of, for example, photolithography (as used in the semiconductor industry) include photomasks, pellicles, and imaging fluids. Photovoltaics (PV) have reflective, refractive, anti-reflective, or encapsulating elements. To produce the desired optical function, both photolithography and photovoltaics rely on the structure-property relationships of materials and precise manufacturing methods. Ancillary properties of interest are latent image formation and development for photoresists and adhesion and environmental isolation for PV encapsulants. We will see how photolithography has been the dominant contributor to the continuous shrinkage of semiconductors, and, with photovoltaics, we will examine how PVs compete with current energy sources by potentially reducing the cost per kWh through technological advancement. Optimization of the optical, physical and economic performance of these materials and elements, including sufficient durability over their required lifetime, is a critical challenge for technological success. Higher performance materials and novel optical elements and system designs, coupled with increased PV module lifetimes and lower degradation rates, are important paths to cost-competitive PV electricity. We will also study the manner in which the evolution of technology has defined and driven the roadmaps of these optical technologies (Moore's Law). The course will include two computational optics labs to design state-of-the-art optical technologies for photolithographic imaging of sub-wavelength semiconductor device feature sizes, and of non-imaging concentrating photovoltaic systems with high optical efficiencies.

EMSE 409. Deformation Processing. 3 Units.

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. Recommended preparation: EMSE 303.

EMSE 411. Environmental Effects on Materials. 3 Units.

Oxidation, corrosion and modification of structure of properties of metallic, ceramic and carbonaceous materials in environments of air, gases and aqueous electrolytes at low and high temperatures; Coatings and other protection methods; Material selection for self-passivation. Conversion-reactions and anodizing for beneficial applications.

EMSE 413. Fundamentals of Materials Engineering and Science. 3 Units.

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 in Extreme Environments. 3 Units.

Fundamentals of degradation pathways of materials under extreme conditions; thermodynamic stability of microstructures, deformation mechanisms, and failure mechanisms. Extreme conditions that will typically be addressed include: elevated temperatures, high-strain rates (ballistic), environmental effects, nuclear radiation, and small scales. Examples will be drawn from recent events as appropriate.

EMSE 421. Fracture of Materials. 3 Units.

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. Recommended preparation: ENGR 200 and EMSE 303 or EMSE 427; or consent.

EMSE 426. Semiconductor Thin Film Science and Technology. 3 Units.

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. Recommended preparation: EMSE 314 or 343.

EMSE 427. Dislocations in Solids. 3 Units.

Elasticity and dislocation theory; dislocation slip systems; kinks and dislocation motion; jogs and dislocation interactions, dislocation dissociation and stacking faults; dislocation multiplication, applications to yield phenomena, work hardening and other mechanical properties.

EMSE 428. Meso-scale Science Including Nanotechnology. 3 Units.

Mesoscale science focuses on addressing the frontiers of complex systems, between quantum and classical, nano and macro, and across the four dimensions of space and time. Nanoscience continues to advance, and multi-scale approaches are used to bridge orders of magnitude in length scales. This course will explore tools that are needed to bridge different length scales, including crystallography (crystal symmetries, point groups, crystal systems and space groups), crystal chemistry, characterization of microstructures (including grains, inclusions, second phases, texture, and voids), diffraction principles and their application in characterizing materials at differing length scales (nano, micro, meso, macro), device characterization methods, and fabrication technologies and processes. Offered as: EMSE 328 and EMSE 428. Prereq: (MATH 223 or MATH 227) and (EMSE 276 or EMSE 201).

EMSE 429. Crystallography and Crystal Chemistry. 3 Units.

Crystal symmetries, point groups, translation symmetries, space lattices, crystal classes, space groups, crystal chemistry, crystal structures and physical properties.

EMSE 435. Strategic Metals and Materials for the 21st Century. 3 Units.

This course seeks to create an understanding of the role of mineral-based materials in the modern economy focusing on how such knowledge can and should be used in making strategic choices in an engineering context. The history of the role of materials in emerging technologies from a historical perspective will be briefly explored. The current literature will be used to demonstrate the connectedness of materials availability and the development and sustainability of engineering advances with examples of applications exploiting structural, electronic, optical, magnetic, and energy conversion properties. Processing will be comprehensively reviewed from source through refinement through processing including property development through application of: titanium, beryllium, molybdenum, cobalt, vanadium, manganese, tantalum, rhenium, and rare earth group metals. The concept of strategic recycling, including design for recycling and waste stream management will be considered. Offered as EMSE 335 and EMSE 435. Prereq: Senior standing or graduate student.

EMSE 443. Materials for Electronics and Photonics. 3 Units.

This course covers the basics of planar processing, which is the foundation of producing semiconductor chips and photonic devices, and the way these devices are incorporated into electronics and display technologies. Basic characteristics of semiconductors and optoelectronic devices; and how advances in these technologies arise from, and drive, advances in materials and device architecture. Offered as: EMSE 343 and EMSE 443. Prereq: (PHYS 122 or PHYS 124) and (EMSE 276 or EMSE 201).

EMSE 463. Magnetism and Magnetic Materials. 3 Units.

This course covers the fundamentals of magnetism and application of modern magnetic materials especially for energy and data storage technologies. The course will focus on intrinsic and extrinsic magnetic properties, processing of magnetic materials to achieve important magnetic performance metrics, and the state-of-the-art magnetic materials used today. The topics related to intrinsic properties, include: magnetic dipole moments, magnetization, exchange coupling, magnetic anisotropy and magnetostriction. Topics related to extrinsic properties, include: magnetic hysteresis, frequency dependent magnetic response and magnetic losses. Technologically important permanent magnets (including rare earth containing alloys and magnetic oxides), soft magnets (including electrical steels, amorphous, ferrites, and nanocrystalline alloys), and thin film materials (including iron platinum) will be discussed in the context of their technological interest. Throughout the course, experimental techniques and data analysis will be discussed. The course is suitable for most graduate students and advanced undergraduates in engineering and science.

EMSE 499. Materials Science and Engineering Colloquium. 0 - 1 Units.

Invited speakers deliver lectures on topics of active research in materials science. Speakers include researchers at universities, government laboratories, and industry. Course is offered both of 1 credit and 0 credits. Attendance is required for both, and graded coursework in the form of a term paper is required when registering for 1 credit. Offered as EMSE 499 and EMSE 599.

EMSE 500T. Graduate Teaching II. 0 Units.

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. Recommended preparation: Ph.D. student in Materials Science and Engineering.

EMSE 502. Mechanical Properties of Metals and Composites. 3 Units.

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. Recommended preparation: ENGR 200 and EMSE 303 or EMSE 421; or consent.

EMSE 503. Structure of Materials. 3 Units.

The structure of materials and physical properties are explored in terms of atomic bonding and the resulting crystallography. The course will cover basic crystal chemistry, basic crystallography (crystal symmetries, point groups, translation symmetries, space lattices, and crystal classes), basic characterization techniques and basic physical properties related to a materials structure.

EMSE 504. Thermodynamics of Solids. 3 Units.

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 505. Phase Transformations, Kinetics, and Microstructure. 3 Units.

Phase diagrams are used in materials science and engineering to understand the interrelationships of composition, microstructure, and processing conditions. The microstructure and phases constitution of metallic and nonmetallic systems alike are determined by the thermodynamic driving forces and reaction pathways. In this course, solution thermodynamics, the energetics of surfaces and interfaces, and both diffusional and diffusionless phase transformations are reviewed. The development of the laws of diffusion and its application for both melts and solids are covered. Phase equilibria and microstructure in multicomponent systems will also be discussed.

EMSE 509. Conventional Transmission Electron Microscopy. 3 Units.

Introduction to transmission electron microscopy-theoretical background and practical work. Lectures and laboratory experiments cover the technical construction and operation of transmission electron microscopes, specimen preparation, electron diffraction by crystals, electron diffraction techniques of TEM, conventional TEM imaging, and scanning TEM. Examples from various fields of materials research illustrate the application and significance of these techniques. Recommended preparation: Consent of instructor.

EMSE 511. Failure Analysis. 3 Units.

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. Recommended preparation: EMSE 201 and EMSE 303 and ENGR 200; or consent.

EMSE 512. Advanced Techniques of Transmission Electron Microscopy. 3 Units.

Theory and laboratory experiments to learn advanced techniques of transmission electron microscopy, including high-resolution transmission electron microscopy (HRTEM), convergent-beam electron diffraction (CBED), microanalysis using X-ray energy-dispersive spectroscopy (XEDS) and electron energy-loss spectroscopy (EELS), and electron-spectroscopic imaging (ESI) for elemental mapping. Recommended preparation: EMSE 509.

EMSE 514. Defects in Semiconductors. 3 Units.

Presentation of the main crystallographic defects in semiconductors; point defects (e.g., vacancies, interstitials, substitutional and interstitial impurities), line defects (e.g., dislocations), planar defects (e.g., grain boundaries). 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 techniques including TEM, EBIC, CL, DLTS, etc. Recommended preparation: EMSE 426.

EMSE 515. Analytical Methods in Materials Science. 3 Units.

Microcharacterization techniques of materials science and engineering: SPM (scanning probe microscopy), SEM (scanning electron microscopy), FIB (focused ion beam) techniques, SIMS (secondary ion mass spectrometry), EPMA (electron probe microanalysis), XPS (X-ray photoelectron spectrometry), and AES (Auger electron spectrometry), ESCA (electron spectrometry for chemical analysis). The course includes theory, application examples, and laboratory demonstrations.

EMSE 599. Materials Science and Engineering Colloquium. 0 - 1 Units.

Invited speakers deliver lectures on topics of active research in materials science. Speakers include researchers at universities, government laboratories, and industry. Course is offered both of 1 credit and 0 credits. Attendance is required for both, and graded coursework in the form of a term paper is required when registering for 1 credit. Offered as EMSE 499 and EMSE 599.

EMSE 600T. Graduate Teaching III. 0 Units.

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. Recommended preparation: Ph.D. student in Materials Science and Engineering.

EMSE 601. Independent Study. 1 - 18 Unit.**EMSE 633. Special Topics. 1 - 18 Unit.****EMSE 649. Special Projects. 1 - 18 Unit.****EMSE 651. Thesis M.S.. 1 - 18 Unit.**

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 Unit.

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. Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

Department of Mechanical and Aerospace Engineering

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 and Bachelor of Science in Engineering with a major in mechanical engineering. Both curricula are based on four-year programs of preparation for productive engineering careers or further academic training. The Bachelor of Science degree program in Mechanical Engineering and the Bachelor of Science degree program in Aerospace Engineering are accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

Departmental Mission

The mission of the Mechanical and Aerospace Engineering Department is to educate and prepare students at both the undergraduate and graduate levels for leadership roles in the fields of Mechanical Engineering and Aerospace Engineering and to conduct research for the benefit of society.

The undergraduate program emphasizes fundamental engineering science, analysis and experiments 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 (including engineering ethics and the role of engineering in society) led by concerned educators and researchers.

The academic and research activities of the department center on the roles of mechanics, thermodynamics, heat and mass transfer, and engineering design in a wide variety of applications such as aeronautics, astronautics, biomechanics and orthopedic engineering, biomimetics and biological inspired robotics, energy, environment, machinery dynamics, mechanics of advanced materials, nanotechnology and tribology. Many of these activities involve strong collaborations with the Departments of Biology, Electrical Engineering and Computer Science, Materials Science and Engineering and Orthopaedics of the School of Medicine.

The significant constituencies of the Mechanical and Aerospace Engineering Department are the faculty, the students, the alumni and the external advisory boards. The educational program objectives are established and reviewed on an ongoing basis based on the feedback from the various constituencies as well as archival information about the program graduates. The faculty engages in continuing discussions of the academic programs in the regularly scheduled faculty meetings throughout the academic year. Periodic surveys of alumni provide data regarding the preparedness and success of the graduates as well as guidance in program development. Archival data include the placement information for graduating seniors, which provides direct information regarding the success of the graduates in finding employment or being admitted to graduate programs.

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.
- 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.

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.

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.

Research

Aerospace Technology and Space Exploration

Flow in turbomachinery, molecular dynamics simulation of rarefied gas flow, two phase flow, supersonic combustion and propulsion, thermoacoustic refrigeration, in-situ resource utilization from space. 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 and Energy

Hydrogen ignition and safety, catalytic combustion, flame spread, fire research and protection, combustion in micro- and partial gravity.

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.

Heat Transfer

Analysis of heat transfer in complex systems such as biological organisms, multi-functional materials and building enclosures.

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.

Multiphase Flow Research

Application of non-intrusive laser based diagnostic techniques and ultrasound techniques including pulsed ultrasound Doppler velocimetry to study solid-liquid, solid-gas, liquid-gas and solid-liquid-gas, multiphase flows encountered in slurry transport and bio-fluid mechanics.

Nanotechnology

Research related to various nanotechnology applications with particular emphasis on energy conversion, generation and storage in nanostructured materials including the synthesis of polymer-based nanocomposites. Current research projects include investigation of nanocomposites for thermoelectric devices, molecular simulation of thermal transport across interfacial regions, and biomimetic research on protein-based shark gel.

Musculoskeletal Mechanics and Materials Research

Design, modeling, and failure analysis of orthopaedic prostheses and material selection; mechanical properties of, and transport processes in, bone and soft tissue; tribology of native and tissue engineered cartilage; nondestructive mechanical evaluation of tissue engineered cartilage.

Robotics

Biologically inspired and biologically based design and control of legged robots. Dynamics, control and simulation of animals and robots.

Tribology and Seals

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 with application to oil-free turbomachinery. Evaluation of advanced seal concepts and configurations for high temperature applications in gas turbine engines.

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.

Bachelor of Science in Engineering

Program Educational Objectives: Aerospace Engineering

- **Objective 1** - Graduates will enter and successfully engage in careers in Aerospace Engineering and other professions appropriate to their background, interests, and skills.
- **Objective 2** - Graduates will engage in continued learning through post-baccalaureate education and/or professional development in engineering or other professional fields.

- **Objective 3** - Graduates will develop as leaders in their chosen professions.

Program Educational Objectives: Mechanical Engineering

- **Objective 1** - Graduates will enter and successfully engage in careers in Mechanical Engineering and other professions appropriate to their background, interests, and skills.
- **Objective 2** - Graduates will engage in continued learning through post-baccalaureate education and/or professional development in engineering or other professional fields.
- **Objective 3** - Graduates will develop as leaders in their chosen professions

Student Outcomes

As preparation for achieving the above educational objectives, the B.S. degree programs in Aerospace Engineering and Mechanical Engineering are designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The Bachelor of Science in Mechanical Engineering and the Bachelor of Science in Aerospace Engineering degree programs are accredited by the Engineering Accreditation Commission of ABET, www.abet.org

Bachelor of Science in Engineering

Major in Aerospace Engineering

Major Courses

EMAE 160	Mechanical Manufacturing	3
EMAE 181	Dynamics	3
EECS 246	Signals and Systems	4
EMAE 250	Computers in Mechanical Engineering	3
EMAE 285	Mechanical Engineering Measurements Laboratory	4
ECIV 310	Strength of Materials	3
EMAE 325	Fluid and Thermal Engineering II	4
EMAE 350	Mechanical Engineering Analysis	3

EMAE 355	Design of Fluid and Thermal Elements	3
EMAE 356	Aerospace Design	3
EMAE 359	Aero/Gas Dynamics	3
EMAE 376	Aerostructures	3
EMAE 382	Propulsion	3
EMAE 383	Flight Mechanics	3
EMAE 384	Orbital Dynamics	3
EMAE 398	Senior Project	3
One technical elective		3
For the Engineering Core natural science and math requirement		3
PHYS 221	Introduction to Modern Physics	
Total Units		57

Bachelor of Science in Engineering Suggested Program of Study: Major in Aerospace Engineering

First Year	Units	
	Fall	Spring
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121) ^d	4	
General Physics I - Mechanics (PHYS 121) ^d	4	
Elementary Computer Programming (ENGR 131) ^{b,d}	3	
FSCC 100 SAGES First Seminar	4	
PHED 101 Physical Education Activities	0	
Calculus for Science and Engineering II (MATH 122) ^d		4
General Physics II - Electricity and Magnetism (PHYS 122) ^d		4
Chemistry of Materials (ENGR 145) ^{b,d}		4
University Seminar ^d		3
PHED 102 Physical Education Activities		0
Year Total:	19	15

Second Year	Units	
	Fall	Spring
Mechanical Manufacturing (EMAE 160) ^d	3	
Dynamics (EMAE 181) ^d	3	
Statics and Strength of Materials (ENGR 200) ^{b,d}	3	
Calculus for Science and Engineering III (MATH 223) ^d	3	
Computers in Mechanical Engineering (EMAE 250) ^d	3	
Introduction to Circuits and Instrumentation (ENGR 210) ^{b,d}	4	
Introduction to Modern Physics (PHYS 221) ^d		3
Elementary Differential Equations (MATH 224) ^d		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225) ^{b,d}		4
University Seminar ^d		3
Year Total:	15	17

Third Year	Units	
	Fall	Spring
Humanities or Social Science elective	3	
Fluid and Thermal Engineering II (EMAE 325)	4	
Mechanical Engineering Measurements Laboratory (EMAE 285) ^d	4	
Strength of Materials (ECIV 310) ^d	3	
Mechanical Engineering Analysis (EMAE 350)	3	
Humanities or Social Science elective		3
Aero/Gas Dynamics (EMAE 359)		3
Aerostructures (EMAE 376)		3
Open elective ^d		3
Technical elective ^d		3
Year Total:	17	15

Fourth Year	Units	
	Fall	Spring
Humanities or Social Science elective	3	
Signals and Systems (EECS 246)	4	
Design of Fluid and Thermal Elements (EMAE 355) ^d	3	
Flight Mechanics (EMAE 383)	3	
Orbital Dynamics (EMAE 384)	3	
Humanities or Social Science elective		3
Aerospace Design (EMAE 356)		3
Propulsion (EMAE 382)		3
Senior Project (EMAE 398) ^{b,d}		3
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)		3
Year Total:	16	15
Total Units in Sequence:		129

Hours required for graduation: 129

- b Engineering Core Course
- d May be taken fall or spring semester.

Bachelor of Science in Engineering Major in Mechanical Engineering

Major Courses		
EMAE 160	Mechanical Manufacturing	3
EMAE 181	Dynamics	3
EECS 246	Signals and Systems	4
EMAE 250	Computers in Mechanical Engineering	3
EMAE 260	Design and Manufacturing I	3
EMAE 285	Mechanical Engineering Measurements Laboratory	4
ECIV 310	Strength of Materials	3
EMAE 325	Fluid and Thermal Engineering II	4
EMAE 350	Mechanical Engineering Analysis	3
EMAE 355	Design of Fluid and Thermal Elements	3
EMAE 360	Design and Manufacturing II	3

EMAE 370	Design of Mechanical Elements	3
EMAE 398	Senior Project	3
Four technical electives		12
Total Units		54

Bachelor of Science in Engineering

Suggested Program of Study: Major in Mechanical Engineering

First Year	Units	
	Fall	Spring
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121) ^d	4	
General Physics I - Mechanics (PHYS 121) ^d	4	
Elementary Computer Programming (ENGR 131) ^{b,d}	3	
FSCC 100 First Seminar	4	
PHED 101 Physical Education Activities	0	
Calculus for Science and Engineering II (MATH 122) ^d		4
General Physics II - Electricity and Magnetism (PHYS 122) ^d		4
University Seminar ^d		3
Chemistry of Materials (ENGR 145) ^{b,d}		4
PHED 102 Physical Education Activities		0
Year Total:	19	15

Second Year	Units	
	Fall	Spring
University Seminar	3	
Statics and Strength of Materials (ENGR 200) ^{b,d}	3	
Mechanical Manufacturing (EMAE 160) ^d	3	
Calculus for Science and Engineering III (MATH 223)	3	
Computers in Mechanical Engineering (EMAE 250) ^d	3	
EMAE 260 - Design and Manufacturing I		3
Dynamics (EMAE 181) ^d		3
Elementary Differential Equations (MATH 224) ^d		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225) ^{b,d}		4
Science elective ^d		3
Year Total:	15	16

Third Year	Units	
	Fall	Spring
Humanities or Social Science elective	3	
Fluid and Thermal Engineering II (EMAE 325)	4	
Mechanical Engineering Measurements Laboratory (EMAE 285) ^d	4	
Strength of Materials (ECIV 310) ^d	3	
Mechanical Engineering Analysis (EMAE 350)	3	
Humanities or Social Science elective		3
Introduction to Circuits and Instrumentation (ENGR 210) ^{b,d}		4

Technical elective ^d		3
Design of Mechanical Elements (EMAE 370)		3
Technical elective ^d		3
Year Total:	17	16

Fourth Year	Units	
	Fall	Spring
Humanities or Social Science elective	3	
Signals and Systems (EECS 246)	4	
Design of Fluid and Thermal Elements (EMAE 355) ^d	3	
Design and Manufacturing II (EMAE 360)	3	
Open Elective ^d	3	
Humanities or Social Science elective		3
Technical elective ^d		3
Senior Project (EMAE 398) ^{b,d}		3
Professional Communication for Engineers (ENGL 398)		3
& Professional Communication for Engineers (ENGR 398)		3
Technical elective ^d		3
Year Total:	16	15
Total Units in Sequence:		129

Hours required for graduation: 129

b Engineering Core Course

d May be taken fall or spring semester.

Technical Electives By Program

Aerospace Engineering: For students following the Design and Manufacturing Track (see requirements for Design and Manufacturing below)

- All 200-, 300-, and 400-level courses from the following areas: EMAE all, EMAE cross-listed, EBME all, EBME cross-listed, ECIV all, EECS all, EECS cross-listed, & EMAC all
- All 300- and 400-level course in ECHE and EMSE areas
- All 300-level MATH and STAT courses with the concurrence of the advisor
- NOTE: We are **not** accepting EMSE 201 as a technical elective

Mechanical Engineering: For students following the Design and Manufacturing Track (See requirements for Design and Manufacturing below)

- All 200-, 300-, and 400-level courses from the following areas: EMAE all, EMAE cross-listed, EBME all, EBME cross-listed, ECIV all, EECS all, EECS cross-listed, & EMAC all
- All 300- and 400-level course in ECHE and EMSE areas
- All 300-level MATH and STAT courses with the concurrence of the advisor
- NOTE: We are **not** accepting EMSE 201 as a technical elective

Science Electives for Mechanical Engineering Majors

The Student Information System is currently set up to accept PHYS 221 Introduction to Modern Physics or STAT 312 Basic Statistics for Engineering and Science as a science elective. Other courses for individual students can be selected with the approval of the student's advisor and the chair using an Academic Advisement Requirement Form (<http://www.case.edu/provost/ugstudies/ARcorrection.pdf>).

Humanities and Social Science Requirements

Consult the Office of Undergraduate Studies section (<http://bulletin.case.edu/undergraduatestudies>) in this bulletin.

Double Major Mechanical and Aerospace Engineering

The department also offers a double major in Mechanical and Aerospace Engineering. The course selection details are provided in the course listing section. The number of additional courses required can vary from six or two courses depending upon the student's program of study.

Five Year Program of Study

The department curriculum offers a five-year cooperative (co-op) education program and a combined bachelors-masters programs which may be completed in five years. 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 in the middle of the sophomore year and normally 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.

The combined bachelors/masters program allows a student to double count 9 credit hours of graduate course work towards the Bachelor of Science degree in any one of the department's two degree programs. By completing the remaining graduate credit hours and a thesis, a student may earn a Master of Science degree in mechanical or aerospace engineering. This may take 5 years or a little longer. 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.

Another option is the 5 year TiME Program taught in conjunction with the Weatherhead School of Management in which a student completes a BS in Aerospace or Mechanical Engineering and earns a Master of Engineering Management.

Minor in Mechanical Design and Manufacturing

A minor in Mechanical Design and Manufacturing is offered to students with an interest in design and manufacturing. The minor consists of an approved set of five EMAE courses.

Required Courses:		
EMAE 160	Mechanical Manufacturing	3
EMAE 260	Design and Manufacturing I	3
EMAE 370	Design of Mechanical Elements	3
		9
Two of the following:		6

EMAE 290	Computer-Aided Manufacturing	3
EMAE 372	Structural Materials by Design	4
EMAE 390	Advanced Manufacturing Technology	3
EMAE 397	Independent Laboratory Research (can be used as an elective in this minor sequence under the following conditions)	1 - 3
1). Student writes a one-page proposal clearly explaining how the project involves mechanical design and/or manufacturing at an advanced undergraduate level.		
2). The proposal is approved by both the student's major advisor, and the EMAE advisor for the mechanical design and manufacturing minor.		
Total Units		15

Graduate Programs

Master of Science in Engineering Research- or Project-Oriented

For a research-oriented MS, each candidate must complete a minimum of 27 hours of graduate-level credits, including at least 18 hours of graduate-level courses and 9 credit hours of MS thesis research.

For the project-oriented option, students must complete 27 credit hours distributed in either of three ways: 21, 24, or 27 credit hours (7, 8 or 9 courses) of approved graduate course work and 6, or 3 credit hours of project replacing the MS thesis.

Course Oriented

Each MS candidate must complete 27 hours of graduate-level credits. The candidate has to pass a comprehensive examination upon completion of the course work.

In addition, a BS/MS program and a 5-year TiME program (BS/ Master of Engineering Management) are also offered for our undergraduate students as indicated in the preceding section.

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 choose to take it in the fall or spring semesters. The minimum course requirements for the PhD degree are as follows:

Depth Courses

All programs of study must include 6 graduate level mechanical courses in mechanical engineering or aerospace engineering. 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 dissertation advisor to meet the objectives of the dissertation research topic.

Breadth and Basic Science Courses

A minimum of six graduate courses are required to fulfill the breadth and basic science courses. The basic science requirement is satisfied by taking two courses in the area of science and mathematics. Four additional courses are needed to provide the breadth outside the student's area of research.

Dissertation Research

All doctoral programs must include a minimum of 18 credit hours of thesis research, EMAE 701 Dissertation Ph.D..

Residence and Teaching Requirements

All doctoral programs must meet the residency requirements of the School of Graduate Studies and the teaching requirements of the Case School of Engineering.

Master of Science in Engineering with Specialization

Fire Science and Engineering

The Case School of Engineering at Case Western Reserve University offers an MS graduate program in Fire Science and Engineering. Students will choose either a Master of Science in Mechanical Engineering or a Master of Science in Macromolecular Science and Engineering, both with a concentration in fire science. Case Western Reserve offers a unique intersection of expertise in macromolecular and combustion science and mechanical and chemical engineering, making us singularly suited to cover all aspects of fire protection, safety and flammability.

Through a 27-credit-hour curriculum, students explore and learn how to apply the fundamental principles of fire behavior and dynamics, protection and suppression systems, polymeric materials structure, properties and selection and more. The program is designed to be completed in a single 12 month year, but can be spread out over multiple years.

The Fire Science and Engineering program at Case Western Reserve covers all aspects of combustion and fire suppression. After graduating from this degree program, students will be ready to apply their thorough understanding of:

- The chemistry of fire and materials
- Flammability logistics
- Fire dynamics and fire behavior
- Fire risk assessment
- Fire protection engineering
- Combustion
- Fire and safety-related codes
- Human behavior and life safety analysis
- Structural fire protection
- Passive fire protection systems
- Polymer engineering

Elective tracks:

- Mechanical track to focus on mechanical engineering and combustion related to fire protection and suppression

- Materials track to focus on polymer chemistry and materials, and the chemistry of flammability and fire suppression

Degree Options

The Fire Science and Engineering master's degree program comprises 27 credit hours of classwork (9 courses) and a research paper. Students can choose to receive a Master of Science in Mechanical Engineering with a concentration in Fire Science and Engineering or a Master of Science in Macromolecular Science and Engineering with a concentration in Fire Science and Engineering.

All students will take six core Fire Science and Engineering courses as well as three courses within their chosen elective track of mechanical engineering or macromolecular science and engineering. The mechanical track follows a traditional mechanical engineering/combustion approach to fire protection and suppression, but with specialization classes in polymers. The materials track focuses on polymer chemistry and materials, and the chemistry of flammability and fire suppression.

For additional information, please contact:

David Schiraldi, Chair of the Department of Macromolecular Science and Engineering

James S. Tien, Leonard Case Jr. Professor of Engineering in Mechanical and Aerospace Engineering

How to Apply

Application to the Fire Science and Engineering program is handled through the university's School of Graduate Studies. Students will need to know whether they wish to apply for the MS in Mechanical Engineering or the MS in Macromolecular Science and Engineering.

Students interested in applying to the Fire Science and Engineering program should already have a bachelor's degree in Chemistry, Chemical Engineering, Mechanical Engineering or Materials Science & Engineering and have taken the GRE. Additional application requirements include a statement of objectives, academic transcripts, and three letters of recommendation. International students will also need to take the Test of English as a Foreign Language (TOEFL). Read more about the university's full application procedure requirements [here](#).

When you are ready to apply, electronic applications can be submitted [here](#).

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 Bingham Student Workshop, the Reinberger Product and Process Development Laboratory, and the Reinberger 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 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.

Distributed Intelligence and Robotics Laboratory

The Distributed Intelligence and Robotics Laboratory (DIRL) is a new laboratory in the Department of Mechanical and Aerospace Engineering that facilitates research activities on robotics and mechatronics. The primary research focuses on distributed intelligence, multi-agent systems, biologically-inspired robotics and medical applications. The laboratory is currently being constructed to house self-sufficient facilities and equipment for designing, testing and preliminary manufacturing. The DIRL also conduct theoretical research related to design methodology and control algorithms based on information theory, complexity analysis and group theory.

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 moiré microscope 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.

Multiphase Flow and Laser Diagnostics Laboratory

A laser diagnostics laboratory is directed toward investigation of complex two-phase flow fields involved in energy-related areas, bio-fluid mechanics of cardiovascular systems, slurry flow in pumps and thermoacoustic power and refrigeration systems. The laboratory is equipped with state-of-the-art Particle Image Velocimetry (PIV) equipment, Pulsed Ultrasound Doppler Velocimeter, Ultrasound concentration measurement instrumentation and modern data acquisition and analysis equipment including PCs. The laboratory houses a clear centrifugal slurry flow pump loop and heart pump loop. Current research projects include investigation of flow through micro-chip devices, CSF flow in ventricles, investigation of solid-slurry flow in centrifugal pumps using ultrasound technique and PIV, thermo-acoustic refrigeration for space application.

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 rotor vibrations 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 that has been ongoing for more than 40 years. 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 hardware and software, and specialized test apparatus for analysis of

joint kinematics. The Bio-imaging Laboratory includes microscopes and three-dimensional imaging equipment for evaluating tissue microstructure and workstations for three-dimensional visualization, measurement and finite element modeling. 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. The Soft Tissue Biomechanics lab includes several standard and special test machines. Instrumentation and a Histology facilities support the activities within the Musculoskeletal Mechanics and Materials Laboratories

National Center for Space Exploration Research

The National Center for Space Exploration Research (NCSER) is a collaborative effort between the Universities Space Research Association (USRA), Case Western Reserve University (CWRU), and NASA Glenn Research Center (GRC) that provides GRC with specialized research and technology development capabilities essential to sustaining its leadership role in NASA missions. Expertise resident at NCSER includes reduced gravity fluid mechanics, reduced gravity combustion processes; heat transfer, two-phase flow, micro-fluidics, and phase change processes; computational multiphase fluid dynamics, heat and mass transfer, computational simulation of physico-chemical fluid processes and human physiological systems. This expertise has been applied to:

- Cryogenic fluid management
- Spacecraft fire safety
- Energy storage
- Thermal management and control
- ISS experiment development
- Astronaut health
- In situ resource utilization
- Materials synthesis
- Fluid structural interaction and tissue mechanics in physiological systems
- Orbit repair of electronics
- Exploration life support
- Dust managements
- Environmental monitoring/control
- Integrated system health monitoring
- Planetary surface mobility
- Bio-fluid mechanics
- Biosystems modeling

nanoEngineering Laboratory

The nanoEngineering Laboratory focuses on research related to various nanotechnology applications with particular emphasis on energy conversion, generation and storage in nanostructured and bio-inspired materials. Synthesis of polymer-based nanocomposites, nanofluids and individual nanostructures is accomplished with tools available in the laboratory. Furthermore, the laboratory houses various pieces of equipment for thermal and electrical characterization of these materials. Research projects include investigation of nanocomposites for thermoelectric devices, molecular simulation of thermal transport across interfacial regions, characterization of nanomaterials for thermal

management (of electronics and buildings) as well as thermal insulation applications, and biomimetic research on a protein-based shark gel.

Other Experimental Facilities

The department facilities also include several specialized laboratories.

Engineering Services Fabrication Center offers complete support to assist projects from design inception to completion of fabrication. Knowledgeable staff is available to assist Faculty, Staff, Students, Researchers, and personnel associated with Case Western Reserve University.

The Bingham Student Workshop is a 2380 sq.ft. facility complete with machining, welding, metal fabrication, and woodworking equipment. This facility is available for the Case undergrads in Mechanical Engineering. Before gaining access to the shop all ME students are required to take the EMAE 172, Mechanical Manufacturing course. This course gives the student a foundation in basic machining, welding, sheet metal fabrication, and safety. Manual drafting, design, and computer-aided drafting is also included in the course. After completion the student can use the shop for other Mechanical Engineering courses requiring prototypes. The BSW, is also, used for senior projects and student organizations, such as, the SAE Baja and Formula and the Design Build and Fly.

The Harry A. Metcalf Laboratory in Glennan Hall Room 422, which was made possible through the generous gift of Sylvia Lissa to honor her late husband and Mechanical Engineering graduate, Class of 1903, has recently been renovated and updated. The restructuring of the computational lab and adjacent experimental lab takes advantage of the Case School of Engineering's Virtual Desktop Infrastructure built on Citrix XenDesktop via gigabit networking. This high-speed networking provides access to software packages including SolidWorks, PTC Creo, MasterCam, Abaqus, MatLab, Microsoft Office, Mathematica, LabView, and many others. The lab is set up to allow the students to use their laptops or ones provided in the lab by the Department for course and project work. As a result of using the Virtual Desktop Infrastructure, engineering students will also be able to access the engineering software listed above from anywhere on any device. Students' home drives are automatically mapped as well when using the virtual applications so that they have access to their files at all times on any device.

The Reinberger Design Studio includes a total of 33 Wyse terminals for Undergraduate Student design use. The Studio is tied directly to the campus network allowing information to be shared with the HAMCL and other network resources. The Studio is used for the instruction of the SolidWorks 2005 CAD software, MasterCam 9.0 CAM software, Solidworks CAD/CAM/FEA software, and Algor 16.1 FEA software. The RDS also offers a 3D Systems SLA 250 and a Dimension machine for generating SLA models from CAD models.

The Reinberger Product and Process Development Laboratory is 1600 square feet of laboratory and office space dedicated to computer-aided engineering activities. The computer numerical control (CNC) laboratory includes both two industrial sized machine tools with additional space for lecture and group project activities. The CNC machine tools located in the laboratory are; a HAAS VF3 4 axis-machining center, a HAAS 2 axis lathe. A Mitutoyo coordinate measuring machine (CMM) located in its own laboratory space completes the facilities. The CMM enables students to inspect their manufactured components to a very degree of precision. The laboratory is used to support both undergraduate and graduate manufacturing courses (EMAE 390, EMAE 490).

High Performance Computing

For high performance computing the department uses the CWRU high performance computing cluster (HPCC). The HPCC consists of 112 compute nodes with Intel Pentium 4 Xeon EM64T processors. All nodes are interconnected with Gigabit Ethernet for MPI message passing and all nodes are interconnected by a separate Ethernet for the purpose of out-of-band cluster management. The MAE Department also has a direct access to all the Ohio Supercomputing Center and all NSF supercomputing centers, primarily to the Pittsburgh Supercomputing Center. Computing-intensive research projects can obtain an account on those supercomputers through their advisers. Research projects carried on in cooperation with the NASA Glenn Research Center can have access to NASA computing facilities. Sophisticated, extensive, and updated general and graphics software are available for applications in research and classroom assignments.

Faculty

Dwight T. Davy, PhD, PE
(University of Iowa)

Professor Emeritus and Interim Chair

Muskulo-skeletal biomechanics; applied mechanics

Jaikrishnan R. Kadambi, PhD
(University of Pittsburgh)

Professor and Associate Chair

Experimental fluid mechanics; multiphase flows; laser diagnostics; bio-fluid mechanics; turbomachinery

Alexis R. Abramson, PhD
(UC Berkeley)

Associate Professor

Macro/micro/nanoscale heat transfer and energy transport

Maurice L. Adams, PhD
(University of Pittsburgh)

Professor

Dynamics of rotating machinery; nonlinear dynamics; vibration; tribology; turbomachinery

Ozan Akkus, PhD

(Case Western Reserve University)

Professor

Nano biomechanics; biomedical devices; biomaterials; fracture mechanics

Paul Barnhart, PhD

(Case Western Reserve University)

Associate Professor

Aerospace engineering, aerospace design

Sunniva Collins, PhD, FASM

(Case Western Reserve University)

Associate Professor

Design for manufacturing, steel metallurgy, heat treatment, surface engineering, fatigue analysis, fatigue of metals, welding, material analytical methods

Malcolm N. Cooke, PhD

(Case Western Reserve University)

Associate Professor

Advanced manufacturing systems; computer integrated manufacturing

Umut A. Gurkan, PhD

(Purdue University)

Assistant Professor

Micro-and nano-scale technologies, biomanufacturing, cell mechanics, and microfluidics

Yasuhiro Kamotani, PhD

(Case Western Reserve University)

Professor

Experimental fluid dynamics; heat transfer; microgravity fluid mechanics

Kiju Lee, PhD

(John Hopkins University)

Nord Distinguished Assistant Professor

Robotics; distributed system design and control; modular robotics; multi-body dynamical systems

Bo Li, PhD

(California Institute of Technology)

Assistant Professor

Solid and computational mechanics, meshfree methods, failure processes in solids, biomechanics, thermal-fluid structure interaction and high performance computing

Joseph M. Mansour, PhD

(Rensselaer Polytechnic Institute)

Professor

Biomechanics; applied mechanics

Joseph M. Prah, PhD, PE

(Harvard University)

Professor

Fluid dynamics; heat transfer; tribology

Vikas Prakash, PhD

(Brown University)

Professor

Experimental and computational solid mechanics; dynamic deformation and failure; time resolved high-speed friction; ultra-high speed manufacturing processes; ballistic penetration of super alloys; engine fan-blade containment, nanomechanics

Roger D. Quinn, PhD

(Virginia Polytechnic Institute & State University)

Arthur P. Armington Professor of Engineering

Biologically inspired robotics; agile manufacturing systems; structural dynamics, vibration and control

Clare M. Rimnac, PhD

(Lehigh University)

Wilbert J. Austin Professor of Engineering

Biomechanics; fatigue and fracture mechanics

James S. Tien, PhD

(Princeton University)

Leonard Case Jr. Professor of Engineering

Combustion; propulsion, and fire research

Emeritus Faculty

Dwight T. Davy, PhD, PE
(University of Iowa)
Professor Emeritus

Musculo-skeletal biomechanics; applied mechanics

Isaac Greber, PhD
(Massachusetts Institute of Technology)
Professor Emeritus

Fluid dynamics; molecular dynamics and kinetic theory; biological fluid mechanics; acoustics

Thomas P. Kicher, PhD
(Case Institute of Technology)
Arthur P. Armington Professor Emeritus of Engineering

Elastic stability; plates and shells; composite materials; dynamics; design; failure analysis

Simon Ostrach, PhD, PE
(Brown University)

Wilbert J. Austin Distinguished Professor Emeritus of Engineering
Fluid mechanics; heat transfer; micro-gravity phenomena; materials processing; physicochemical hydrodynamics

Eli Reshotko, PhD
(California Institute of Technology)

Kent H. Smith Emeritus Professor of Engineering
Fluid Dynamics; heat transfer, propulsion; power generation

Research Faculty

Richard J. Bachmann, PhD
(Case Western Reserve University)
Assistant Research Professor
Biologically inspired robotics

R. Balasubramaniam, PhD
(Case Western Reserve University)
Research Associate Professor, National Center for Space Exploration Research
Microgravity fluid mechanics

Uday Hegde, PhD
(Georgia Institute of Technology)
Research Associate Professor, National Center for Space Exploration Research
Combustion, turbulence and acoustics

Mohammad Kassemi, PhD
(University of Akron)
Research Associate Professor, National Center for Space Exploration Research
Computational fluid mechanics

Vedha Nayagam, PhD
(University of Kentucky)
Research Associate Professor, National Center for Space Exploration Research
Low gravity combustion and fluid physics

Fumiaki Takahashi, PhD
(Keio University)
Research Associate Professor, National Center for Space Exploration Research
Combustion, fire research, laser diagnostics

Associated Faculty

Michael Adams, PhD
(Case Western Reserve University)
Adjunct Instructor
Cleveland State University

J. Iwan D. Alexander, PhD
(Washington State University)
Adjunct Professor

Ali Ameri, PhD
(The Ohio State University)
Adjunct Assistant Professor
Computational Fluid Dynamics

Christos C. Chamis, PhD
(Case Western Reserve University)
Adjunct Professor; NASA Glenn Research Center
Structural analysis; composite materials; probabilistic structural analysis; testing methods

James Drake, BSE
(Case Western Reserve University)
Adjunct Instructor

Christopher Hernandez, PhD
(Stanford University)
Adjunct Assistant Professor
Musculoskeletal biomechanics, solid mechanics and medical device design

Meng-Seng Liou, PhD
(University of Michigan)
Adjunct Professor; NASA Glenn Research Center
Computational fluid mechanics; aerodynamics; multi-objective optimization

Kenneth Loparo, PhD
(Case Western Reserve University)
Professor of Electrical Engineering and Computer Science
Control; robotics; stability of dynamical systems; vibrations

David Matthiesen, PhD
(Massachusetts Institute of Technology)
Associate Professor of Materials Science Engineering
Microgravity crystal growth

Wyatt S. Newman, PhD
(Massachusetts Institute of Technology)
Professor of Electrical Engineering and Computer Science
Mechatronics; high-speed robot design; force and vision-based machine control; artificial reflexes for autonomous machines; rapid prototyping; agile manufacturing

Mario Garcia Sanz, PhD
(University of Navarra)
Professor of Electrical Engineering and Computer Science
Systems and control, spacecraft controls, automated manufacturing

Chih-Jen Sung, PhD
(Princeton University)
Adjunct Professor; University of Connecticut
Combustion, propulsion, laser diagnostics

Ravi Vaidyanathan, PhD
(Case Western Reserve University)
Adjunct Assistant Professor
Robotics and control

Xiong Yu, PhD, PE
(Purdue University)
Assistant Professor
Geotechnical engineering, non-destructive testing, intelligent infrastructures

Courses

EMAE 160. Mechanical Manufacturing. 3 Units.

The course is taught in two sections-Graphics and Manufacturing. Manufacturing To introduce manufacturing processes and materials and their relationships to mechanical design engineering. Course includes hands-on machining and metal fabrication lab. Also, each lab creates a 'virtual' field trip of a manufacturing facility to be shared with the class. Graphics Development of mechanical engineering drawings in orthographic, sectional, and pictorial views using manual drafting and computer-aided drafting (CAD software), dimensioning, tolerancing geometric dimensioning and tolerancing and assembly drawings will also be covered. All students are paired up to give a Manufacturing Design Presentation demonstrating the course material. The course has two (75) minute lectures and one (110) minute Machining Lab per week.

EMAE 181. Dynamics. 3 Units.

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. Recommended preparation: MATH 122 and PHYS 121 and ENGR. 200

EMAE 250. Computers in Mechanical Engineering. 3 Units.

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. Recommended preparation: ENGR 131 and MATH 122.

EMAE 260. Design and Manufacturing I. 3 Units.

This is the second course of a 4-course sequence focusing on "Engineering Design and Manufacturing." This course develops students' competence and self-confidence as design engineers by exposing the students to design as a creative process and its relationship with modern manufacturing practices. The outcomes of the course focus on the student's ability to apply their knowledge of mathematics, science, and engineering to design a system, component, or process that meets desired needs within realistic, multi-dimensional constraints, such as: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Additionally, students will be given the opportunity to identify, formulate, and solve engineering problems, while applying professional and ethical practices. Professional communication skills are emphasized and expected during all stages of the design process. The course has five main areas of emphasis: design as a creative process, decision-based design methodologies, project management, engineering economics, and design for manufacture (CAD/CAM/CAE) using industrial software tools. The course exposes the student to the integration of engineering design, manufacturing, and management disciplines and includes activities to consider and understand the complex processes associated with controlling and managing product data through all stages of the product life-cycle (PLM). Topics include: engineering ethics, design as a creative process, design methodologies, project management, engineering economics, product life-cycle management (PLM), CAD/CAE/CAM, and the role of digital manufacturing within the design process. Design/Rapid Prototyping Studio activities are an integral part of the course, and enable the students to be part of a design and build team working on various project-based tasks. Prereq: EMAE 160 or EMAE 172.

EMAE 282. Mechanical Engineering Laboratory I. 2 Units.

Techniques and devices used for experimental work in mechanical and aerospace engineering. Lecture topics include elementary statistics, linear regression, propagation of uncertainty, digital data acquisition, characteristics of common measurement systems, background for measurement laboratories, and elements of report writing. Hands-on laboratory experiences may include measurements in solid mechanics, dynamics, and fluid and thermal sciences, which are summarized in group reports. At least one report will focus on design of a measurement. Specific lecture and measurement topics will be chosen for each student on a case-by-case basis. Only students who have taken EMAE 283 but not EMAE 282 may take EMAE 282.

EMAE 283. Mechanical Engineering Laboratory II. 2 Units.

Techniques and devices used for experimental work in mechanical and aerospace engineering. Lecture topics include elementary statistics, linear regression, propagation of uncertainty, digital data acquisition, characteristics of common measurement systems, background for measurement laboratories, and elements of report writing. Hands-on laboratory experiences may include measurements in solid mechanics, dynamics, and fluid and thermal sciences, which are summarized in group reports. At least one report will focus on design of a measurement. Specific lecture and measurement topics will be chosen for each student on a case-by-case basis. Only students who have taken EMAE 282 but not EMAE 283 may take EMAE 283.

EMAE 285. Mechanical Engineering Measurements Laboratory. 4 Units.

Techniques and devices used for experimental work in mechanical and aerospace engineering. Lecture topics include elementary statistics, linear regression, propagation of uncertainty, digital data acquisition, characteristics of common measurement systems, background for measurement laboratories, and elements of report writing. Hands-on laboratory experiences may include measurements in solid mechanics, dynamics, and fluid and thermal sciences, which are summarized in group reports. At least one report will focus on design of a measurement. Recommended preparation: EMAE 181, ENGR 225 and ECIV 310.

EMAE 290. Computer-Aided Manufacturing. 3 Units.

An advanced design and manufacturing engineering course covering a wide range of topics associated with the 'design for manufacturability' concept. Students will be introduced to a number of advanced solid modeling assignments (CAD), rapid prototyping (RP), and computer-aided manufacturing (CAM). In addition students will be introduced to computer numerical control (CNC) manual part-programming for CNC milling and turning machine tools. All students will be given a design project requiring all detail and assembly drawings for a fully engineered design. The course has two (50) minute lectures and one (110) minute CAD/CAM Lab per week. Prereq: EMAE 160.

EMAE 325. Fluid and Thermal Engineering II. 4 Units.

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. Recommended preparation: ENGR 225.

EMAE 350. Mechanical Engineering Analysis. 3 Units.

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. Recommended preparation: MATH 224.

EMAE 352. Thermodynamics in Energy Processes. 3 Units.

Thermodynamic properties of liquids, vapors and real gases, thermodynamic relations, non-reactive mixtures, psychometrics, combustion, thermodynamic cycles, compressible flow. Prereq: ENGR 225.

EMAE 355. Design of Fluid and Thermal Elements. 3 Units.

Synthesis of fluid mechanics, thermodynamics, and heat transfer. Practical design problems originating from industrial experience. Recommended preparation: ENGR 225 and EMAE 325.

EMAE 356. Aerospace Design. 3 Units.

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 Units.

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. Recommended preparation: ENGR 225 and EMAE 325.

EMAE 360. Design and Manufacturing II. 3 Units.

This is the third course of a 4-course sequence focusing on "Engineering Design and Manufacturing," and is the senior capstone design course focused on a semester-long design/build/evaluate project. The course draws on a student's past and present academic and industrial experiences and exposes them to the design and manufacture of a product or device that solves an open-ended "real world" problem with multidimensional constraints. The course is structured and time-tabled within the Case School of Engineering (CSE) to give the EMAE 360 students the opportunity to team with students from other CSE departments (e.g., BME and EECS) to form multidisciplinary design teams to work on the solution to a common problem. The outcomes of the course continue to focus on the student's ability to function on multidisciplinary teams while applying their knowledge of mathematics, science and engineering to design a system, component, or process that meets desired needs within realistic, multidimensional constraints, such as: economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability. Professional communication skills are emphasized and expected during all stages of the design process and will include formal and informal oral presentations, periodic peer-focused design reviews, and a development through its various evolutionary stages to completion. Counts as SAGES Senior Capstone. Prereq: EMAE 160 or EMAE 172, and EMAE 260.

EMAE 363. Mechanical Engineering Modern Analysis Methods. 4 Units.

This is a required mechanical engineering course to develop an in-depth fundamental understanding of current analysis software tools, as well as to develop an ability to perform practical analyses using current software tools to analyze assigned industrial case studies for the following topical areas: (1) mechanism synthesis, (2) finite element analyses for stress and deflection, (3) machinery vibration, and (4) computational fluid dynamics. It is comprised of three lectures and one software application laboratory period per week. Prereq: ENGR 225, EMAE 181, EMAE 250, and ECIV 310.

EMAE 370. Design of Mechanical Elements. 3 Units.

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. Recommended preparation: ECIV 310 and EMAE 271.

EMAE 372. Structural Materials by Design. 4 Units.

Materials selection and design of mechanical and structural elements with respect to static failure, elastic stability, residual stresses, stress concentrations, impact, fatigue, creep, and environmental conditions. Mechanical behavior of engineering materials (metals, polymers, ceramics, composites). Influence of ultrastructural and microstructural aspects of materials on mechanical properties. Mechanical test methods. Models of deformation behavior of isotropic and anisotropic materials. Methods to analyze static and fatigue fracture properties. Rational approaches to materials selection for new and existing designs of structures. Failure analysis methods and examples, and the professional ethical responsibility of the engineer. Four mandatory laboratories, with reports. Statistical analysis of experimental results. Recommended Preparation: EMSE 276. Offered as EMAE 372 and EMSE 372. Prereq: ENGR 200.

EMAE 376. Aerostructures. 3 Units.

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. Recommended preparation: ECIV 310.

EMAE 377. Biorobotics Team Research. 3 Units.

Many exciting research opportunities cross disciplinary lines. To participate in such projects, researchers must operate in multi-disciplinary teams. The Biorobotics Team Research course offers a unique capstone opportunity for undergraduate students to utilize skills they developed during their undergraduate experience while acquiring new teaming skills. A group of eight students form a research team under the direction of two faculty leaders. Team members are chosen from appropriate majors through interviews with the faculty. They will research a biological mechanism or principle and develop a robotic device that captures the actions of that mechanism. Although each student will cooperate on the team, they each have a specific role, and must develop a final paper that describes the research generated on their aspect of the project. Students meet for one class period per week and two 2-hour lab periods. Initially students brainstorm ideas and identify the project to be pursued. They then acquire biological data and generate robotic designs. Both are further developed during team meetings and reports. Final oral reports and a demonstration of the robotic device occur in week 15. Offered as BIOL 377, EMAE 377, BIOL 477, and EMAE 477. Counts as SAGES Senior Capstone.

EMAE 378. Mechanics of Machinery I. 3 Units.

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. Recommended preparation: EMAE 370. Offered as EMAE 378 and EMAE 478.

EMAE 382. Propulsion. 3 Units.

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. Recommended preparation: ENGR 225.

EMAE 383. Flight Mechanics. 3 Units.

Aircraft performance: take-off and landing, unaccelerated flight, range and endurance, flight trajectories. Aerodynamics and propulsion. Aircraft static stability and control, simple maneuvers. Aircraft flight dynamics and control, flight simulation. Prereq: EMAE 181, EMAE 325, EMAE 359, EECS 304.

EMAE 384. Orbital Dynamics. 3 Units.

Spacecraft 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. Rigid body dynamics, altitude dynamics and control, simulations.

EMAE 387. Vibration Problems in Engineering. 4 Units.

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. Recommended preparation: MATH 224 and EMAE 181.

EMAE 390. Advanced Manufacturing Technology. 3 Units.

This course will focus on advanced design and manufacturing technologies and systems, with an emphasis on the total product life cycle and the challenges of secure and efficient product data management. Topics will include: traditional and rapid subtractive and additive prototyping and manufacturing technologies, design for manufacture (DFM), control and quality assurance of the design and manufacturing process, manufacturing system integration, "Globalization," and sustainable engineering. The course will be project-based and laboratory sessions will take place in the Reinberger and think[box] studios. Prereq: EMAE 290.

EMAE 396. Special Topics in Mechanical and Aerospace Engineering. 1 - 18 Unit.

(Credit as arranged.)

EMAE 397. Independent Laboratory Research. 1 - 3 Unit.

Independent research in a laboratory.

EMAE 398. Senior Project. 3 Units.

Individual or team design or experimental project under faculty supervisor. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Recommended preparation: Senior standing, EMAE 360, and consent of instructor. Counts as SAGES Senior Capstone.

EMAE 399. Advanced Independent Laboratory Research/Design. 1 - 3 Unit.

Students perform advanced independent research or an extended design project under the direct mentorship of the instructor. Typically performed as an extension to EMAE 397 or EMAE 398. Prereq: EMAE 397.

EMAE 400T. Graduate Teaching I. 0 Units.

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. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 401. Mechanics of Continuous Media. 3 Units.

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 Units.

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. Recommended preparation: EMAE 181 or equivalent. Offered as EBME 422 and EMAE 402.

EMAE 414. Nanobiomechanics in Biology. 3 Units.

This course will elucidate the forces at play at the level of proteins including those associated with mass, stiffness, viscosity, thermal and chemical factors. Basic polymer mechanics within the context of biological molecules will be covered and structures of key proteins associated with mechanical functions, such as actin, myosin and the cell membrane will be explained. Generation of force by polymerization of filamentous proteins as well as motor proteins will be included. Interaction forces between proteins, DNA/RNA mechanics will also be elucidated. Besides lectures, there will be term long project assignments (outreach-based or detailed literature survey on a subject associated with nanomechanics of cells/proteins). Recommended Preparation: Mechanics of Materials, Thermodynamics, Statics, Introductory Level Differential Equations, Introductory Level Fluid Mechanics.

EMAE 415. Introduction to Musculo-skeletal Biomechanics. 3 Units.

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. Recommended preparation: EMAE 181 and ECIV 310.

EMAE 421. Multiscale Modeling of Bio- and Bio-inspired Systems. 3 Units.

Depending on who you ask, the topic of Multiscale Computational Modeling is either a hot topic or passé; multiscale modeling is either a key to deciphering cellular mechanisms, e.g., of organismal mechanobiology, or an impossibility due to the necessity of unlimited access to super computers and ultrahigh resolution imaging that allow for explicit definition of organ scale events at subcellular length and time scales (and that require access to data storage of greater than terabyte scale databases). If you ask me, we are already "doing multiscale modeling", but new computational and experimental approaches are presenting opportunities to reach the goal of tying organ scale mechanical loading (physiological loading events) to cellular mechanisms of e.g. tissue modeling and remodeling during development, growth, aging, as well as in health and disease. In this graduate level class we will address one particular mechanobiological system as a case study (Spring 2013: Bone as a Biosystem) and then extrapolate approaches to student-driven, relevant biological, bio-inspired and medical problems. Typically graduate students participating in the class are developing computational models as part of their graduate research; tying the in the class topics to the student's research modeling serves as the "lab" for this class and the student reports on these activities both in class as well as in the initial review paper, the multiscale model to be developed by the student, and the final class paper which should be prepared for submission to a relevant journal. Students will keep a lab/modeling notebook throughout the course to develop the ideas and concepts introduced in the course in context of their own bio- or bio-inspired system of interest. The biological system of interest and the problem to be addressed will be developed using typical engineering problem approach rubrics (problem statement/ hypothesis, governing equations, idealizations/assumptions, initial & boundary conditions, knows/unknowns, in-/dependent variables) to predict system behavior using a comp model. Recommended Preparation: Senior undergraduates in engineering recommended to have completed ENGR 225 and ECIV 310 and an engineering GPA above 3.25. Prereq: Senior undergraduates in Engineering, GPA greater or equal to 3.25.

EMAE 424. Introduction to Nanotechnology. 3 Units.

An exploration of emerging nanotechnology research. Lectures and class discussion on 1) nanostructures: superlattices, nanowires, nanotubes, quantum dots, nanoparticles, nanocomposites, proteins, bacteria, DNA; 2) nanoscale physical phenomena: mechanical, electrical, chemical, thermal, biological, optical, magnetic; 3) nanofabrication: bottom up and top down methods; 4) characterization: microscopy, property measurement techniques; 5) devices/applications: electronics, sensors, actuators, biomedical, energy conversion. Topics will cover interdisciplinary aspects of the field. Offered as EECS 424 and EMAE 424.

EMAE 450. Advanced Mechanical Engineering Analysis. 3 Units.

This course is intended to equip students with tools for solving mathematical problems commonly encountered in mechanical, fluid and thermal systems. Specific goals are to: i) Enable the student to properly categorize the problem in a variety of ways ii) Enable the student to identify appropriate approaches to solving the problem ii) Provide the student experience in applying some common methods for obtaining numerical solutions iii) Provide the student with understanding of trade-offs and expectations for the methods used. The course covers topics related to analytical and computational approaches to problems categorized in a variety of ways including: 1. Linear versus nonlinear problems 2) finite degrees of freedom v. infinite degrees of freedom, 3) equilibrium v. propagation v. eigenvalue problems, 4) direct formulations v. indirect formulations 5) analytical v. numerical solutions. The course will be built around specific examples from solid mechanics, dynamics, vibrations, heat transfer and fluid mechanics. The significance of the various categorizations will be developed as an ongoing part of the approach to solving the problems. Prereq: EMAE 350 or Requisites Not Met permission.

EMAE 453. Advanced Fluid Dynamics I. 3 Units.

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 Units.

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. Recommended preparation: EMAE 453.

EMAE 455. Advanced Thermodynamics. 3 Units.

Basic ideas of thermodynamics and dominant methods of their development: operational, postulational, and statistical. Entropy and information theory. Irreversible thermodynamics. Applications.

EMAE 456. Micro-Electro-Mechanical Systems in Biology and Medicine (BioMEMS). 3 Units.

Microscale technologies have enabled advanced capabilities for researchers in unexplored territories of cells in biology and medicine. Biological (or Biomedical) Micro-Electro-Mechanical Systems (BioMEMS) involve the fundamentals of mechanics, electronics and advanced microfabrication technologies with specific emphasis on biological applications. BioMEMS is an interdisciplinary research area which brings together multiple disciplines including, mechanical engineering, biomedical engineering, chemical engineering, materials science, electrical engineering, clinical sciences, medicine, and biology. BioMEMS based technologies have found real world applications in tissue engineering, implantable microdevices, proteomics, genomics, molecular biology, and point-of-care platforms. This course aims to: (1) introduce the need for miniaturized systems in biology and medicine and the fundamental design and microfabrication concepts, (2) introduce the basics of microscale manipulation of cells and biological agents employing the fundamentals of microscale behaviors of fluids and mechanical systems, (3) expose the students to applications of BioMEMS and on-chip technologies in biology and medicine with clinical impact. Recommended Preparation: ENGR 200, ENGR 225, EMAE 285, BIOL 325, EECS 424, and ECHE 483.

EMAE 457. Combustion. 3 Units.

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 459. Advanced Heat Transfer. 3 Units.

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. Recommended preparation: EMAE 453.

EMAE 460. Theory and Design of Fluid Power Machinery. 3 Units.

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. Recommended preparation: Consent of instructor.

EMAE 461. Chemistry of Fire Safe Polymers and Composites. 3 Units.

Chemistry of Fire Safe Polymers and Composites starts with the introduction of characterization techniques used for fire safe materials and combustion phenomena research. General discussion on how reduced flammability of polymers and composites are obtained, for example by additives and preparing intrinsically thermally stable chemical structure and some examples of smart approaches, will be discussed. It also discusses the synthetic methods of preparing high temperature stable polymers in addition to the raw materials used to prepare those materials. Special emphasis will be placed on the thermal stability data obtained by thermogravimetric analysis (TGA) and combustion calorimetry for those fire safe materials. Mechanistic aspects of the flammability of polymers will be explained with special emphasis on the molar contribution of chemical functionality to the heat release capacity. Theoretical derivation of thermokinetic parameters will be explained. In addition, a common sense build-up will be attempted by providing actual numbers associated with those thermokinetic parameters. Upon completion of background formation, a more advanced materials, composites and nanocomposites, will be discussed using the results recently reported. Preliminary attempts to explain flame retardation by nanocomposite structures will also be discussed. Offered as EMAC 461 and EMAE 461.

EMAE 466. Mechanics of Biological Fluids. 3 Units.

This is a senior/graduate level course which aims to provide a solid grasp of the role of mechanics in biological fluids and in the human circulatory system that will help in the research and design of new medical instruments, equipment, and procedures. The course will cover properties of Newtonian and non-Newtonian fluids, hydrostatic and dynamic forces, principles of continuity, conservation of mass, energy and momentum and their applications in biological fluids, laminar and turbulent flows and boundary layer, introduction to Navier Stokes, dimensional analysis and similarity, blood flow in the cardiovascular system, gas exchange in the pulmonary system, blood flow in microcirculation and vessels. Important concepts will be covered by case studies.

EMAE 477. Biorobotics Team Research. 3 Units.

Many exciting research opportunities cross disciplinary lines. To participate in such projects, researchers must operate in multi-disciplinary teams. The Biorobotics Team Research course offers a unique capstone opportunity for undergraduate students to utilize skills they developed during their undergraduate experience while acquiring new teaming skills. A group of eight students form a research team under the direction of two faculty leaders. Team members are chosen from appropriate majors through interviews with the faculty. They will research a biological mechanism or principle and develop a robotic device that captures the actions of that mechanism. Although each student will cooperate on the team, they each have a specific role, and must develop a final paper that describes the research generated on their aspect of the project. Students meet for one class period per week and two 2-hour lab periods. Initially students brainstorm ideas and identify the project to be pursued. They then acquire biological data and generate robotic designs. Both are further developed during team meetings and reports. Final oral reports and a demonstration of the robotic device occur in week 15. Offered as BIOL 377, EMAE 377, BIOL 477, and EMAE 477. Counts as SAGES Senior Capstone.

EMAE 478. Mechanics of Machinery I. 3 Units.

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. Recommended preparation: EMAE 370. Offered as EMAE 378 and EMAE 478.

EMAE 480. Fatigue of Materials. 3 Units.

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 Units.

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. Recommended preparation: EMAE 181.

EMAE 487. Vibration Problems in Engineering. 3 Units.

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. Recommended preparation: EMAE 181 and MATH 224.

EMAE 488. Advanced Robotics. 3 Units.

This course will focus on up-to-date knowledge and theories related to robotics and multi-agent systems. Related mathematics and theories including group theory (Lie groups), rigid-body motions (SO(3) and SE(3)), kinematics, dynamics, and control will be studied. In addition, the class will also discuss structural, computational and task complexity in robotic systems based on combinatorial analysis, information theory, and graph theory. Lecture and discussion topics: Kinematics; Introduction to Group Theory and Lie Groups; Rigid-body Motions (SO(3), SE(3)); Multi-body Dynamical Systems: Order-N computational methods; Complexity Analysis for Robotic Systems; Structural complexity, information-theoretic complexity, and task complexity; Special Discussion Topics; Special discussion topics may vary each year. Students enrolled in this class will be required to conduct a final project. Two or three students will work as a team. The topics for student teams may include: computer simulation of multi-body dynamical systems, art robot design, and complexity analysis for coupled complex systems. The detailed information will be provided in the first week of the class. The final presentations and demonstrations will be held during the last week of class and will be open to the public audience. Students are also required to submit a final report following a IEEE conference paper template. Prereq: EMAE 181, EECS 246.

EMAE 489. Robotics I. 3 Units.

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. Recommended preparation: EMAE 181. Offered as EECS 489 and EMAE 489.

EMAE 500T. Graduate Teaching II. 0 Units.

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. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 501. Constitutive Modeling of Solids. 3 Units.

Fundamentals of constitutive modeling of deformable solids. Hyper-elastic, viscoelastic, plastic, and viscoplastic material responses and how microstructural mechanisms influence the macroscopic mechanical behavior in different materials. The course also aims at equipping students with necessary background to develop constitutive models that can be used in commercial/research finite element software for the analysis of complex structures and components. Prereq: EMAE 401.

EMAE 540. Advanced Dynamics II. 3 Units.

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 Units.

Nonlinear oscillations; including equations of Duffings, van der Pol, Hill, and Mathieu; and perturbation solution approaches. Bifurcation and jump phenomena, strange attractors, chaos. Poincare maps and related engineering applications.

EMAE 554. Turbulent Fluid Motion. 3 Units.

Mathematics and physics of turbulence. Statistical (isotropic, homogeneous turbulence) theories; success and limitations. Experimental and observational (films) evidence. Macrostructures and microturbulence. Other theoretical approaches. Recommended preparation: EMAE 454.

EMAE 557. Convection Heat Transfer. 3 Units.

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. Recommended preparation: EMAE 453 and EMAE 454.

EMAE 558. Conduction and Radiation. 3 Units.

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. Recommended preparation: Consent of instructor.

EMAE 570. Computational Fluid Dynamics. 3 Units.

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.

EMAE 600T. Graduate Teaching III. 0 Units.

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. Recommended preparation: Ph.D. student in Mechanical Engineering.

EMAE 601. Independent Study. 1 - 18 Unit.**EMAE 651. Thesis M.S.. 1 - 18 Unit.****EMAE 657. Experimental Techniques in Fluid and Thermal Engineering Sciences. 3 Units.**

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 Unit.**EMAE 701. Dissertation Ph.D.. 1 - 18 Unit.**

Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.

EMAE C100. Co-Op Seminar I for Mechanical Engineering. 1 Unit.

Professional development activities for students returning from cooperative education assignments. Recommended preparation: COOP 001.

EMAE C200. Co-Op Seminar II for Mechanical Engineering. 2 Units.

Professional development activities for students returning from cooperative education assignments. Recommended preparation: COOP 002 and EMAE C100.

Division of Engineering Leadership and Professional Practice

The Division of Engineering Leadership and Professional Practice (<http://engineering.case.edu/delpp>) (DELPP) designs, develops and administers programs and opportunities which complement and enhance the curricular offerings in the Case School of Engineering.

The DELPP staff is committed to serving all engineering undergraduate and graduate students. We work closely with students, faculty, staff, and off-campus organizational representatives to deliver experiences designed to promote excellence in engineering education.

Mission Statement

The mission of the Division of Engineering Leadership and Professional Practice is to support, through teaching and educational research, the Case School of Engineering's educational programs, student programs, and outreach activities at all academic levels: K-12, undergraduate, graduate, and continuing education.

The activities supported by DELPP include optional academic programs that enhance the engineering curriculum, such as Cooperative Education

and the Dual Degree undergraduate programs, as well as global exchange programs and support of engineering student organizations and programs.

Cooperative Education

Cooperative Education (Co-op) (<http://engineering.case.edu/coop>) is an academic program that enables students to alternate classroom studies with career based experiences in industry. It is a learning experience designed to integrate classroom theory with practical experience and professional development. Co-op is a paid full time work experience designed to maximize the student's education. Case co-op assignments are typically for two seven-month periods, each period consisting of a summer and a contiguous spring or fall semester. This program is available to students who have completed 4-5 semesters of coursework, in good academic standing, registered as a full time student, and pursuing a degree in engineering, engineering physics, physics, biochemistry, biology or chemistry. For additional information, please contact Ms. Mary Rose Tichar (mary.tichar@case.edu) at 216.368.4447.

Dual Degree (3-2) Engineering Program

The Dual Degree (3-2) (<http://engineering.case.edu/delpp/dualdegree>) Engineering Program enables superior students, enrolled at approximately forty participating liberal arts colleges in the continental United States and Puerto Rico, to combine a strong liberal arts foundation with the study of engineering. While enrolled at a cooperating liberal arts college, students complete courses in mathematics, chemistry, physics, and computer science in addition to studies in the humanities and social sciences. Students complete these courses during their first three years and must obtain the approval of the designated faculty liaison at the liberal arts college prior to admission to the Case School of Engineering.

Qualified candidates continue at the Case School of Engineering for an additional two years of concentrated coursework in an engineering field. At the conclusion of five years, two baccalaureate degrees are awarded: one from the liberal arts college and the other a Bachelor of Science degree from Case Western Reserve University. For additional information, please contact Ms. Deborah Fatica (deborah.fatica@case.edu) at 216.368.4449.

Engineering Academic Community Engagement

The DELPP develops strategic and intentional programming designed to engage students and promote a strong and supportive campus community.

Joint activities with faculty, alumni, staff and corporate sponsors include, but are not limited to: leadership opportunities in Engineering student organizations including National Engineers Week, hands-on industry sponsored design competitions, and networking and mentoring with alumni and faculty.

A list of the Engineering student organizations can be found at <http://engineering.case.edu/delpp/studentorgs>. For additional information on the student engagement opportunities, please contact Ms. Genine Apidone (genine.apidone@case.edu) at 216.368.5024.

Global Programs

Global Programs (<http://engineering.case.edu/delpp/global-exchange>) offer international opportunities for engineering students ranging from

study abroad to short-term programs, internships and cooperative education experiences, and research opportunities. Participation in global activities optimizes the student's educational experience as well as contributes to their societal awareness. Exposure to global activities is a very valuable asset for leadership positions within multinational corporations.

The Division of Engineering Leadership and Professional Practice designs and implements programs tailored to students' interests. Currently, short term cultural and language immersion programs are offered in the summer at various international universities, with more being established. At the University of Botswana, a three-week engineering core course is taught, which intertwines engineering content with regional issues specific to sub-Saharan Africa. New programs and opportunities continue to develop for students.

In addition, the Case School of Engineering hosts many students from various countries which enables students to learn about and interact with various cultures.

Students may also be interested in the student chapter of Engineers Without Borders, a national non-profit organization devoted to delivering engineering assistance to developing areas around the world.

Approximately 80% of the Case School of Engineering faculty collaborate with over one hundred universities and organizations in over thirty countries spanning six continents. For additional information, please contact Ms. Deborah Fatica (deborah.fatica@case.edu) at 216.368.4449.

K-12 Outreach

K-12 partnerships are an emerging arm of the DELPP and are managed through the Leonard Gelfand STEM Center (<http://gelfand.case.edu>), a collaboration between the College of Arts and Sciences and the Case School of Engineering. The goals for the Gelfand STEM Center are to (1) increase the number and diversity of students in the STEM disciplines at Case Western Reserve University and elsewhere and (2) increase all students' scientific literacy through a variety of innovative STEM programs. The Gelfand STEM Center leverages the resources of Case Western Reserve University to engage pre-college students, teachers, and families in activities that introduce them to scientific practices and concepts and inspire a lasting interest in science and engineering. For additional information, please contact Ms. Me'lani Joseph (melani@case.edu) at 216.368.1651.

Engineering Physics

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. Its engineering science and design components prepare students to work as professional engineers.

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 is required. The

project includes a written report and participation in the senior seminar and symposium.

Mission and Program Objectives

The mission of the Engineering Physics program is to prepare students for careers in engineering where physics principles can be applied to the advancement of technology. This education at the intersection of engineering and physics will enable students to seek employment in engineering upon graduation while providing a firm foundation for the pursuit of graduate studies in either engineering or physics. The Engineering Physics program will develop sufficient depth in both engineering and physics skills to produce engineers who can relate fundamental physics to practical engineering problems, and will possess the versatility to address new problems in our rapidly changing technological base. The program will provide a curriculum and environment to develop interdisciplinary collaboration, ethical and professional outlooks, communication skills, and the tools and desire for life-long learning.

Program Educational Objectives

1. Graduates of the Engineering Physics program will apply their strong problem solving skills as physicists along with an understanding of the approach, methods, and requirements of engineering and engineering design for a successful career in advancing technology.
2. Graduates of the Engineering Physics program will use their strong skills in problem solving, research experience and knowledge in physics and engineering as successful graduate students and researchers in highly ranked graduate programs.

Program Outcomes

As preparation for achieving the above program educational objectives, the BS degree program in Engineering Physics is designed so that students attain:

- an ability to apply knowledge of mathematics, science, and engineering
- an ability to design and conduct experiments, as well as to analyze and interpret data
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively
- the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- a recognition of the need for, and an ability to engage in life-long learning
- a knowledge of contemporary issues
- an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The Bachelor of Science degree program in Engineering Physics is accredited by the Engineering Accreditation Commission of ABET, www.abet.org (<http://www.abet.org>).

Bachelor of Science in Engineering

Sample Program of Study: Major in Engineering Physics

First Year	Units	
	Fall	Spring
Principles of Chemistry for Engineers (CHEM 111)	4	
Calculus for Science and Engineering I (MATH 121) ^a	4	
General Physics I - Mechanics (PHYS 121) ^b	4	
SAGES First Seminar	4	
PHED Physical Education Activities		
Calculus for Science and Engineering II (MATH 122) ^a		4
General Physics II - Electricity and Magnetism (PHYS 122) ^b		4
Elementary Computer Programming (ENGR 131) ^c		3
Chemistry of Materials (ENGR 145)		4
SAGES University Seminar		3
PHED Physical Education Activities		
Year Total:	16	18

Second Year	Units	
	Fall	Spring
Calculus for Science and Engineering III (MATH 223)	3	
Introduction to Modern Physics (PHYS 221)	3	
Statics and Strength of Materials (ENGR 200)	3	
Introduction to Circuits and Instrumentation (ENGR 210)	4	
SAGES University Seminar	3	
Elementary Differential Equations (MATH 224)		3
Instrumentation and Signal Analysis Laboratory (PHYS 208)		4
Computational Methods in Physics (PHYS 250)		3
Classical Mechanics (PHYS 310)		3
Thermodynamics, Fluid Dynamics, Heat and Mass Transfer (ENGR 225)		4
Year Total:	16	17

Third Year	Units	
	Fall	Spring
Thermodynamics and Statistical Mechanics (PHYS 313)	3	
Engineering Physics Laboratory I (PHYS 317)	3	
Advanced Laboratory Physics Seminar (PHYS 303)	1	
Introduction to Quantum Mechanics I (PHYS 331)	3	
Engineering Concentration ^d	3	
Humanities/Social Science elective	3	
Engineering Physics Laboratory II (PHYS 318)		4
Electricity and Magnetism I (PHYS 324)		3
Professional Communication for Engineers (ENGL 398)		3
& Professional Communication for Engineers (ENGR 398)		
Humanities/Social Science elective		3
Engineering Concentration ^d		3

Year Total: 16 16

Fourth Year	Units	
	Fall	Spring
Electricity and Magnetism II (PHYS 325)	3	
Senior Physics Project Seminar (PHYS 352)	1	
Senior Engineering Physics Project (PHYS 353)	2	
Engineering Concentration ^d	3	
Humanities/Social Science elective	3	
Elective	3	
Senior Physics Project Seminar (PHYS 352)		1
Senior Engineering Physics Project (PHYS 353)		2
Applied Quantum Mechanics ^e		3
Engineering Concentration ^d		3
Humanities/Social Science elective		3
Elective		3
Year Total:	15	15
Total Units in Sequence:		129

Hours required for graduation: 129

- a Selected students may be invited to take MATH 124 Calculus II, MATH 227 Calculus III or MATH 228 Differential Equations in place of MATH 121 Calculus for Science and Engineering I, MATH 122 Calculus for Science and Engineering II, MATH 223 Calculus for Science and Engineering III or MATH 224 Elementary Differential Equations.
- b Selected students may be invited to take PHYS 123 Physics and Frontiers I - Mechanics or PHYS 124 Physics and Frontiers II - Electricity and Magnetism in place of PHYS 121 General Physics I - Mechanics or PHYS 122 General Physics II - Electricity and Magnetism.
- c Students may also choose to fulfill this requirement with EECS 132 Introduction to Programming in Java.
- d 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: Biomedical Engineering (Biomedical Systems and Analysis, Devices and Instrumentation, Biomaterials); Chemical Engineering; Civil Engineering (Solid Mechanics, Structural Engineering, Geotechnical Engineering, Environmental Engineering); Electrical Engineering and Computer Science (Solid State, Computer Science, Computer Engineering-Software, Computer Engineering-Hardware, Systems and Control); Macromolecular Science and Engineering; Materials Science and Engineering; Mechanical and Aerospace Engineering (Aerospace, Mechanics).
- e Students may choose to fulfill this requirement in their third year:
 - PHYS 332 Introduction to Quantum Mechanics II
 - PHYS 327 Laser Physics/PHYS 427 Laser Physics
 - EECS 321 Semiconductor Electronic Devices
 - EMSE 405 Dielectric and Electrical Properties of Materials

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