NORTHWESTERN

Undergraduate Catalog 2011–12

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This catalog for the academic year beginning September 1, 2011, contains University regulations and information about the programs and courses offered by the Robert R. McCormick School of Engineering and Applied Science. Failure to read this catalog does not excuse a student from knowing and complying with its content.

Northwestern University reserves the right to change without notice any statement in this catalog concerning, but not limited to, rules, policies, tuition, fees, curricula, and courses. In exceptional circumstances, Northwestern University reserves the right, at its sole discretion, to waive any documentation normally required for admission. It also reserves the right to admit or deny a student admission whenever it believes that it has sufficient evidence for the decision.

The current version of the Northwestern Undergraduate Catalog can be accessed at **http://www.registrar.northwestern.edu/courses/undergrad_catalog.html#undergraduate_catalog**.

Robert R. McCormick School of Engineering and Applied Science

www.mccormick.northwestern.edu

The McCormick School of Engineering and Applied Science is committed to providing leadership for the technological foundation of our society, economy, environment, and culture. The school's mission is twofold: the personal and professional development of its students and faculty and the development and application of new technology, which is increasingly of an interdisciplinary nature.

McCormick is dedicated to a high standard of excellence in

- Teaching fundamentals of science and engineering disciplines and stimulating students to become innovative thinkers and leaders able to cope with complex issues in a changing environment
- Preparing undergraduate and graduate students capable of understanding, applying, and contributing to technology in whatever areas or careers they subsequently pursue

Undergraduate students in McCormick may follow a curriculum leading to a bachelor of science degree in any of the following fields:

applied mathematics
biomedical engineering
chemical engineering
civil engineering
computer engineering
computer science
electrical engineering
environmental engineering
industrial engineering
manufacturing and design engineering
materials science and engineering
mechanical engineering
medical engineering (Honors Program in Medical Education only)

The programs in biomedical engineering, chemical engineering, civil engineering, computer engineering, electrical engineering, environmental engineering, industrial engineering, manufacturing and design engineering, materials science and engineering, and mechanical engineering are accredited by the Engineering Accreditation Commission of ABET (www.abet.org).

With the proper use and combination of requirements, options, and electives, students may prepare themselves for graduate work in engineering and also for postbaccalaureate degrees in medicine, law, business, or other areas. Bachelor of science degrees are awarded also in approved ad hoc combined studies programs.

Graduate programs of study are available in all of the above fields as well as in theoretical and applied mechanics, biotechnology, engineering design and innovation, computer information systems, manufacturing management, project management, information technology, product development, and engineering management. Programs leading to degrees at the master's and doctoral levels are described completely in the course catalog for the Graduate School and in publications on engineering graduate programs.

Excellence in research is a distinguishing characteristic of the engineering faculty. A faculty such as this, working at the frontiers of knowledge, is in the best position to maintain currency in courses and curricula and to develop an atmosphere inspiring scholarship, discovery, and originality among students.

McCormick has a student body of approximately 1,500 undergraduates and 1,350 graduate students. It is housed in the Technological Institute complex, which contains nearly 2 million square feet of floor area and provides excellent educational and research facilities.

ACADEMIC POLICIES

Requirements for the Degree of Bachelor of Science

Students must successfully complete all 48 units of the curriculum or have equivalent academic credit. Students who interrupt their programs of study for an extended time during which degree requirements are changed will normally be held to the new requirements. Those who encounter curricular changes during their period of enrollment may choose to follow any curriculum during that period but must meet its requirements completely.

All curricula leading to a bachelor of science degree in engineering or applied science have the same basic components: mathematics, engineering analysis and computer proficiency, basic sciences, design and communications, basic engineering, social sciences/humanities, unrestricted electives, and the major program. Courses qualifying for these components are listed in the departments appearing under Academic Offerings (beginning on page 203). General requirements are as follows:

Core Courses (32 units)

Mathematics (4 units)

Standard for all degree programs:

- MATH 220 Differential Calculus of One-Variable Functions
- MATH 224 Integral Calculus of One-Variable Function
- MATH 230 Differential Calculus of Multivariable Functions
- MATH 234 Multiple Integration and Vector Calculus

Note: ES APPM 252-1,2 satisfy requirements for MATH 230 and 234.

Engineering Analysis and Computer Proficiency (4 units)

Standard for all degree programs: GEN ENG 205-1,2,3,4 Engineering Analysis or 206-1,2,3,4 Honors Engineering Analysis

Basic Sciences (4 units)

Eligible courses vary by degree program; 4 courses from at least two of the areas below; no more than 2 from earth and planetary sciences/astronomy; no more than 3 in any other area:

- *Physics*
  - PHYSICS 135-2,3 General Physics
  - PHYSICS 335 Modern Physics for Nonmajors
- *Biological sciences*
  - BIOL SCI 210-1 Genetics and Evolutionary Biology
  - BIOL SCI 210-2 Biochemistry and Molecular Biology
  - BIOL SCI 210-3 Physiology and Cell Biology
  - CHEM ENG 275 Molecular and Cell Biology for Engineers
- C*hemistry*
  - CHEM 101 General Chemistry
  - CHEM 102 General Inorganic Chemistry
  - CHEM 103 General Physical Chemistry
  - CHEM 171 Accelerated General Inorganic Chemistry
  - CHEM 172 Accelerated General Physical Chemistry
  - CHEM 210-1,2 Organic Chemistry
- *Earth and planetary sciences/astronomy*
  - EARTH 201 Surface Processes
  - EARTH 202 Earth's Interior
  - ASTRON 220 Introduction to Astrophysics

Design and Communications (3 units)

Standard for all degree programs (except biomedical engineering, which requires BMD ENG 390-2):

- *Writing and design*
  - DSGN 106-1,2 Engineering Design and Communication (.5 units each)
  - ENGLISH 106-1,2 Writing in Special Contexts (.5 units each)
- *Speaking*
  - GEN CMN 102 Public Speaking, GEN CMN 103 Analysis and Performance of Literature, or BMD ENG 390-2 Biomedical Engineering Design

Basic Engineering (5 units)

Eligible courses vary by degree program; 5 courses from at least four of the following areas:

- *Computer architecture and numerical methods*
  - EECS 203 Introduction to Computer Engineering
  - EECS 205 Fundamentals of Computer System Software
  - EECS 328 Numerical Methods for Engineers
  - ES APPM 346 Modeling and Computation in Science and Engineering
- *Computer programming*
  - EECS 211 Object-Oriented Programming in C++
  - EECS 317 Data Management and Information Processing
  - EECS 230 Programming for Computer Engineers or 231 Advanced Programming for Computer Engineers
- *Electrical science*
  - EECS 202 Introduction to Electrical Engineering
  - EECS 221 Fundamentals of Circuits
  - EECS 222 Fundamentals of Signals and Systems
  - EECS 223 Fundamentals of Solid-State Engineering
  - EECS 224 Fundamentals of Electromagnetics and Photonics
  - EECS 270 Applications of Electronic Devices
  - MECH ENG 233 Electronics Design
- *Fluids and solids*
  - BMD ENG 270 Fluid Mechanics
  - BMD ENG 271 Introduction to Biomechanics
  - CHEM ENG 321 Fluid Mechanics
  - CIV ENV 216 Mechanics of Materials I
  - MECH ENG 241 Fluid Mechanics I
- *Materials science and engineering*
  - MAT SCI 201 Introduction to Materials, 203 Microstructure and Engineering Properties of Materials, or 301 Materials Science Principles
- *Probability, statistics, and quality control*
  - BMD ENG 220 Introduction to Biomedical Statistics
  - CHEM ENG 312 Probability and Statistics for Chemical Engineering
  - CIV ENV 306 Uncertainty Analysis in Civil Engineering
  - EECS 302 Probabilistic Systems and Random Signals
  - IEMS 201 Introduction to Statistics
  - IEMS 303 Statistics
  - MECH ENG 359 Reliability Engineering
- *Systems engineering and analysis*
  - CHEM ENG 210 Analysis of Chemical Process Systems
  - CIV ENV 304 Civil and Environmental Engineering Systems Analysis

- IEMS 310 Operations Research
- IEMS 313 Deterministic Models and Optimization
- IEMS 326 Economics and Finance for Engineers

- *Thermodynamics*
  - BMD ENG 250 Thermodynamics
  - CHEM 342-1 Thermodynamics
  - CHEM ENG 211 Thermodynamics
  - MAT SCI 314 Thermodynamics of Materials
  - MAT SCI 315 Phase Equilibria and Diffusion in Materials
  - MECH ENG 220 Thermodynamics I (may not be taken with CHEM 342-1 or CHEM ENG 211)
  - MECH ENG 370 Thermodynamics II

Social Sciences/Humanities (7 units)
Standard for all degree programs:

- 7 social sciences/humanities courses approved in advance by the McCormick Humanities Panel and chosen according to one of two options:
  - *Option A:* 3 courses must be thematically related. At least 2 courses must be chosen from each of the following areas:
    - *Social and behavioral sciences*
    - *Historical studies and values*
    - *Fine arts, language, and literature*
  - *Option B:* 5 courses must be thematically related; no more than 5 may come from a single area listed above
- For both Options A and B, no more than 3 of the 7 social sciences/humanities courses may be 100-level courses.

Unrestricted Electives (5 units)
Standard for all degree programs: students may take any credit course in the University to explore or extend technical or nontechnical interests.

Major Program (16 units)

Each degree program in the McCormick School finds its depth in the 16 units devoted to the major program. Each curriculum provides considerable elective opportunity within these courses. The intent is to provide opportunity for individualization, but coherence in the selection of elective courses is still necessary. In accredited programs, the understanding is that certain criteria will be met, and guidance to this end is essential. Accordingly, it is required that a plan of study listing intended selections be submitted for approval by the end of the eighth quarter of study (winter quarter of junior year). All 16 units in the major program must be at the 200 level or higher.

Most curricula offer suggested areas of specialization or options that provide excellent guidance in using electives. These course plans are available in the department or program offices or the McCormick Academic Services Office and can be the basis for course planning. Alternately, self-designed plans may be submitted, but they should be worked out in consultation with a faculty adviser.

Students must meet not only McCormick curriculum requirements but also the specific requirements for the program of study being pursued. The listings of these curricula present additional information or specifics to be used with the basic curriculum (see Academic Offerings, page 203).

Some curricula contain specializations or options. These are for advice and guidance for elective course choice. In addition, some courses may be regarded as duplicates (contact the Undergraduate Engineering Office or see the McCormick website for this list), and taking them will increase the number of requirements needed to earn a McCormick degree. For further details about the options or specializations within a particular program, consult with the department coordinator sponsoring that curriculum, check with McCormick's Academic Services Office, or see the school's web page at www.mccormick.northwestern.edu.

Grade Requirements

A grade point average (GPA) of not less than 2.0 is required for all units presented for the degree. Students must have received a grade of C or higher in any course taken elsewhere and used to fulfill a McCormick degree requirement. The GPA of the 16 units in the major program must also be at least 2.0; no more than 2 of these units may carry grades of D.

Every candidate for a degree must file an application for the degree a year in advance of the date of graduation (see Academic Calendar on pages 4–5).

In addition to, and independent of, the requirements set by McCormick, all students must satisfy the Undergraduate Residence Requirement (see page 17).

Pass/No Credit Option

The following requirements apply to the pass/no credit (P/N) option:

- No more than 8 units taken P/N may be counted toward the 48 units required for the degree.
- Only 1 unit per quarter may be taken P/N during freshman and sophomore years.
- *Core courses:* Only 4 100- or 200-level courses may be taken P/N to satisfy the 7-unit requirement in the social sciences/humanities. No courses may be taken P/N in the required mathematics, engineering analysis and computer proficiency, basic sciences, design and communications, and basic engineering areas.
- *Major program:* Consult the responsible department office or McCormick's Academic Services Office regarding the regulations for use of P/N in each departmental program.

- Credits earned under a P/N grading scheme at another institution may be applied toward McCormick requirements only if the P/N option is permissible for that requirement.

Advanced Placement

Advanced placement and college credit may be granted on the basis of the College Entrance Examination Board (CEEB) Advanced Placement tests. Placement or exemption may be granted on the basis of the CEEB tests (or other appropriate international examinations), special examinations in subject areas, or analysis of high school background. Any placement (verified by a grade above C– in a subsequent course) in approved sequential work will reduce the requirements for the BS by the number of courses preceding the placement. These stipulations regarding placement, exemption, and degree requirements may differ from those of other schools of the University. Students receiving credit from Advanced Placement examinations and other such programs must still meet the Undergraduate Residence Requirement.

See the Cross-School Options chapter for opportunities open to all Northwestern undergraduates.

ACADEMIC OPTIONS

Cooperative Engineering Education Program

The Walter P. Murphy Cooperative Engineering Education Program alternates periods of paid industrial experience and academic studies for full-time students in all departments of engineering and applied science. During 18 months of industrial employment, students can apply theory while gaining practical experience. This perspective enables them to develop an understanding of the responsibilities of their future professional careers.

Freshmen are invited to participate in workshops to prepare themselves for the co-op program. Sophomores in good academic standing begin applying for co-op positions as early as the fall quarter. The co-op coordinator makes every effort to secure interviews for the students so that cooperative work assignments are related to their professional objectives.

Generally, the first work experience for sophomore co-op students occurs the summer before their junior year. Co-op experience for juniors, transfer students, and others may begin as late as the spring of junior year. If necessary, with the help of the academic advisers, special schedules may be arranged to enable students to meet individual academic requirements as well as co-op requirements.

Students register for their work quarters, but no tuition or fee is charged. This registration keeps co-op students enrolled at Northwestern during work periods. While no academic credit is given for co-op, special BS/MS programs may use co-op experience as the basis for undergraduate projects and master's theses.

Although emphasis is on the experience gained from cooperative work rather than on the income, students in the co-op program can cover a portion of their educational expenses with their earnings.

The following table shows the college-industry schedule for the five years of undergraduate education:

College-Industry Schedule

	Summer	Fall	Winter	Spring
Freshman		1	2	3
Sophomore	vacation	4	5	6
Junior	work	7	8	work
Presenior	work	9	work	10
Senior	work	work	11	12

Students who complete the co-op plan receive tuition rebates during their final academic quarters to assure that they will not pay higher total tuition than other students in the same entering class.

In addition to the academic degree, McCormick awards co-op students a certificate in recognition of successful completion of the Walter P. Murphy Cooperative Engineering Education Program. Students must successfully complete the schedule of school and work—which meets standards set by the program and the co-op employer—in order to receive recognition as co-op students upon graduation from McCormick.

In some states, co-op experience may be credited for up to one year of the usual four years of engineering experience required for the Professional Engineer's License.

Employers of co-op students include government and service institutions as well as industry. Co-op coordinators visit participating employers periodically to discuss students' abilities, attitudes, and progress on the job. At the end of each work period, employers are asked to evaluate student performance and progress. It is important to note that neither students nor cooperative employers obligate themselves to permanent employment by virtue of the co-op status, although most students get impressive permanent job offers as a result of the co-op experience. Others are admitted to prestigious graduate and professional schools.

Undergraduate Honors Program

Students with good scholastic records may apply to the Undergraduate Honors Program any time during their junior or presenior years. (Students within three quarters of graduation are past this admission point.) At the time of admission, they must have a cumulative GPA of 3.5 or better. Courses used to meet the requirements of the Undergraduate Honors Program must also be used toward requirements for the bachelor's degree.

Honors students participating in the program must

- Complete at least three units of approved advanced study (including courses normally accepted at the graduate level) with an average grade of B or better
- Complete an extended independent study project (at least two quarters on the same topic) leading to an acceptable report

Successful completion of the honors program will be noted on the student's transcript. Recognition also will be given in the Commencement program. If a student's individually evaluated performance is not judged to meet the standards of success, the student will still receive course grades and credits as earned.

Undergraduate Research

Opportunities for undergraduate research are made available and encouraged. Each field of study offers independent study courses for research enrollment on an elective basis.

The Sara Boley Undergraduate Research Fund makes available money for individual research projects.

The Northwestern Student Advisory Board holds an annual competition for the best undergraduate research project, and the winner is recognized with the Harold Benedict Gotaas Award.

Students normally perform undergraduate research projects under the direction of faculty doing research in their department and in laboratories throughout the University, including McCormick research centers. For more on McCormick's research activities, see www.mccormick.northwestern.edu/research.

Combined Studies Program

For students whose particular interests and goals cannot be satisfied by one of the regular programs of study in engineering or applied science, the Combined Studies Program provides an alternative. If endorsed and guided by three faculty members and approved by McCormick's Curriculum Committee, an ad hoc curriculum leading to the bachelor of science degree may be pursued. Students applying to the program must submit their petitions to the McCormick Curriculum Committee 3½ quarters before the completion of their degrees.

Available courses may be combined in a variety of interdisciplinary plans as long as the all-school specification of eight basic components is met. Examples of combined studies programs from recent years include public health, engineering physics, biomedical engineering and molecular biology, and computers and mechanical design.

Students interested in the Combined Studies Program should consult with the associate dean for undergraduate engineering.

Second Field of Specialization

Elective opportunities in the McCormick curriculum may be used toward a departmental program in another school of the University. Satisfactory completion of the requirements for the second program, verified by the appropriate department, will be noted on the student's transcript. Carefully planned electives will normally enable students to obtain a second field of specialization within the 48-unit requirement for the BS degree.

Multiple BS Degrees

Students with wide-ranging interests may work toward two or more bachelor of science degrees in McCormick. The work in additional areas does not need to be completed at the same time, but the full requirements for each degree must be approved by each department or program no later than two academic quarters before the completion of work for the second degree but no earlier than the junior year. The full requirements for each degree must be satisfied. At least 6 additional units of credit, or their equivalent, must be presented before the awarding of each additional degree.

Accelerated Master's Program

Qualified undergraduate students at McCormick may work simultaneously toward the bachelor of science and master of science degrees in engineering. Integrated planning of course work allows the possibility of taking graduate-level courses during the third and fourth years. The requirements remain unchanged for the two degrees. The McCormick requirement for the BS is 48 units, and the requirement for the MS is specified by the individual department (9–12 units). No course used for the MS requirement may be counted toward the BS requirement.

Application for admission to concurrent BS/MS study must be approved by the appropriate department and the Graduate School. A department may require that students do additional work beforehand.

Dual Bachelor's Degree Programs

Dual Engineering and Liberal Arts Degrees

McCormick encourages breadth of interest and to this end supports dual bachelor's degree programs in engineering and liberal arts. A common approach to a dual bachelor's degree program is a parallel arrangement of studies requiring five years and resulting in a BA with a major in Weinberg College and a BS in a particular field of engineering. Students must complete the stated requirements of both schools and expected majors. For a description of the program, see page 29 in the Cross-School Options chapter. For information on applying to the program, see page 11.

Dual Engineering and Music Degrees

Highly capable students who have a strong interest in and commitment to both engineering and music may pursue a five-year program leading to bachelor's degrees in both fields. In engineering any field of study may be chosen, resulting in a bachelor of science in the chosen field. In music the bachelor of music or bachelor of arts in music is awarded. For a description of the program, see page 29 in the Cross-School Options chapter. For information on applying to the program, see page 11.

Business Enterprise Certificate

Students who aim to have business careers and want to improve their ability to make a contribution soon after they graduate may wish to consider pursuing this certificate program. This program involves a combination of required business courses and work experience. Students who complete the Walter P. Murphy Cooperative Engineering Education Program must take 2 units of credit in addition to those needed for their bachelor's degrees; other students must take 4 extra units. An acceptable report on the work experience and successful completion of a McCormick BS degree are required.

Certificate in Engineering Design

This certificate program, administered by the Segal Design Institute, develops a set of design skills that prove valuable in careers across the entire spectrum available to McCormick graduates. See page 227 for details.

Certificate in Entrepreneurship

This certificate, administered by the Farley Center for Entrepreneurship and Innovation, is intended for undergraduates planning to pursue entrepreneurship at some point in their careers. Students who plan to join or create a start-up hone skills to complement their degrees. Students focused on research gain skills relevant when traditional sources of research funding no longer exist and commercialization is the next logical step. The certificate requires completion of 4 courses:

- IEMS 225 Principles of Entrepreneurship
- IEMS 325 Engineering Entrepreneurship
- 2 courses chosen from
    - IEMS 399 Independent Study with Farley Center faculty focusing on a student idea or a project from the Northwestern University Innovation and New Ventures Office
    - ISEN 430 NUvention: Energy
    - IEMS 495 NUvention: Medical
    - EECS 495 NUvention: Web
    - A graduate-level course focused on a technology the student is interested in commercializing
    - A course in economics or business institutions in Weinberg College (requires prior approval from the Farley Center)

Honors Program in Medical Education

The Honors Program in Medical Education (HPME) is designed for unusually gifted high school students who seek a career in medicine or medical science. It provides a plan whereby students entering Northwestern are admitted simultaneously to McCormick, Weinberg College, or the School of Communication and to the Feinberg School of Medicine. HPME students then participate in a challenging program, with the first three or four years in undergraduate study and the last four years in the Feinberg School. Thus, the period of formal training may be reduced by one year.

Students who meet the entrance requirements of McCormick may pursue a program leading to the bachelor of science degree in medical engineering after five years and the doctor of medicine degree after seven years. See page 30 for more information on HPME and page 11 for information on applying to the program.

STUDENT RESOURCES

Tutorial Program

McCormick conducts a program of guided study and tutorial help for freshmen and sophomores in all the required courses in mathematics, chemistry, physics, and engineering. This program encourages out-of-class work and good study habits and helps provide a full understanding of the early courses that are the foundation for much that is to follow. The aim is not to displace students in their learning efforts but to provide explanations to bridge the uncertain or unknown and lead to depth of understanding.

Faculty Advisers

During the first year students are assigned a freshman adviser. At the beginning of the sophomore year most students will have selected a program of study and will be reassigned an adviser in that area. Advisers assist in planning the program of study, but students retain the responsibility of meeting overall graduation requirements. Curricular and other advice may be obtained by addressing an e-mail request to mccormick-school@northwestern.edu.

Organizations for Engineering Students

The McCormick Student Advisory Board is composed of representatives from each class in engineering and from approved McCormick organizations. It is the recognized representative body of undergraduate engineering students and as such serves as a link between the students and faculty and administration. It encourages and coordinates the activities of engineering students and student groups.

The following professional societies have established student branches on the campus:

American Institute of Chemical Engineers
American Society of Civil Engineers
American Society of Mechanical Engineers

ASM International
Association for Computing Machinery
Biomedical Engineering Society
Design for America
Engineers for a Sustainable World
InNUvation
Institute of Electrical and Electronics Engineers and its computer and engineering in medicine and biology subchapters
Institute of Industrial Engineers
Materials Research Society
National Society of Black Engineers
Northwestern Organization of Design Engineers
Society of Automotive Engineers
Society of Hispanic Professional Engineers
Society of Manufacturing Engineers
Society of Women Engineers

The following honorary societies recognize high-achieving McCormick undergraduates:

Eta Kappa Nu: open to upperclass students in electrical engineering who demonstrate superior scholarship and ability
Kappa Theta Epsilon: cooperative engineering education honorary society
Omega Chi Epsilon: for upperclass students in chemical engineering who demonstrate superior scholarship and leadership ability
Phi Eta Sigma: for freshmen who earn a scholastic average equivalent to a grade of A
Phi Lambda Upsilon: open to upperclass students in chemistry and chemical engineering who demonstrate superior scholarship and academic ability
Pi Tau Sigma: for upperclass students in mechanical engineering who demonstrate superior scholarship and leadership ability
Sigma Xi Society: associate membership open to seniors who excel in scholarship in at least two departments
Tau Beta Pi: for upperclass students who have shown superiority in scholarship and ability in engineering work

ACADEMIC OFFERINGS

GENERAL ENGINEERING

Introductory and Related Courses

DSGN 106-1,2 Engineering Design and Communication (.5 unit each) Integrated introduction to the engineering design process and technical communication. Approaches to unstructured and poorly defined problems; conceptual and detailed design; team structure and teamwork; project planning; written, oral, graphical, and interpersonal communications; use of software tools; discussion of societal and business issues. One lecture, two workshops, lab. Registration for both quarters required. Primarily intended for freshmen.

GEN ENG 190-0 Engineering Freshman Seminar Broad engineering or interdisciplinary subjects of current interest.

GEN ENG 191-0 MEOP Complete Seminar Issues unique to minority engineering students. Working in groups, achieving one's full potential, succeeding in class, increasing involvements with faculty and in their research. Primarily intended for freshmen.

GEN ENG 195-1,2,3,4 Engineering Dialog (.33 unit each) A weekly seminar addressing subjects of interest in engineering, design, engineering policy, and entrepreneurial activities. For participants in the invitation-only Murphy Institute Scholars Program. May be repeated.

GEN ENG 205-1,2,3,4 Engineering Analysis **1.** Introduction to linear algebra from computational, mathematical, and applications viewpoints. Computational methods using a higher-level software package such as Matlab. May be taken concurrently with 215-1. **2.** Linear algebra and introduction to vector methods in engineering analysis. Statics and dynamics of rigid bodies and matrix analysis of trusses and networks. Engineering design problems. May be taken concurrently with 215-2. Prerequisites: C– or better in 205-1; MATH 220. **3.** Dynamic behavior of the elements. Modeling of mechanical (both translational and rotational), electrical, thermal, hydraulic, and chemical systems composed of those elements. May be taken concurrently with 215-3. Prerequisite: C– or better in 205-2. **4.** Solution methods for ordinary differential equations, including exact, numerical, and qualitative methods. Applications and modeling principles; solution techniques. May be taken concurrently with 215-4. Prerequisites: C– or better in 205-2; MATH 224.

GEN ENG 206-1,2,3,4 Honors Engineering Analysis Covers topics addressed in 205 at a deeper level. Intended for students with demonstrated strength in mathematics, computer programming, and/or physics. Prerequisite: consent of instructor.

GEN ENG 215-1,2,3,4 Advanced Conceptual Workshop Exercises related to work in 205. Taken concurrently with 205-1,2,3,4.

GEN ENG 220-1,2 Analytic and Computer Graphics (.5 unit each) **1.** Creating in autoCAD software. **2.** 3-D parametric modeling with AutoDesk Inventory.

GEN ENG 295-0 Introductory Topics in Engineering Intermediate-level topics suggested by students or faculty members and approved by the curriculum committee.

CRDV 301-0 Introduction to Career Development (0 units) This course prepares students for the Walter P. Murphy Cooperative Engineering Education Program, internships, and full-time employment. It includes units on job-search skills, self-assessment, transition to the workplace, workplace-management issues, and transition back to school.

CRDV 310-1,2,3,4,5,6 Cooperative Engineering Education (0 units) This sequence of courses covers the work terms of students enrolled in the Walter P. Murphy Cooperative Engineering Education Program. Prerequisite: CRDV 301 or consent of program director.

CRDV 311-1,2,3 Professional Engineering Internship (0 units) This series of courses is designated for students pursuing the Business Enterprise Certificate, seeking University recognition of their internship experience, or participating in an approved internship during the regular academic year. Prerequisite: consent of program director.

CRDV 312-1,2,3 Undergraduate Engineering Projects in Service Learning Noncredit course requiring students to engage in an engineering-related, full-time community service project under the guidance of an appropriate faculty member, agency supervisor, or mentor.

GEN ENG 355-0 Domestic Study—Affiliated Full-time registration in an academic program in the continental United States that is affiliated with Northwestern. Upon successful completion of the program, registration is replaced with credits transferred from the affiliated institution.

GEN ENG 395-0 Special Topics in Engineering Topics suggested by faculty members and approved by the curriculum committee.

GEN ENG 397-0 Selected Topics in Engineering (.5 unit) Topics of limited scope as suggested by faculty members and approved by the curriculum committee.

GEN ENG 399-0 Independent Study Independent study on an engineering subject supervised by a faculty member and concluding with a final report.

APPLIED MATHEMATICS

See Engineering Sciences and Applied Mathematics.

See the Cross-School Options chapter for opportunities open to all Northwestern undergraduates.

BIOMEDICAL ENGINEERING

www.bme.northwestern.edu

Biomedical engineers solve problems in the life sciences and clinical medicine by applying engineering and mathematical techniques. This approach has been fruitful where a descriptive approach is no longer adequate for studying complex systems involved in the body's transport, regulation, and information processing. Equally important has been the development of devices used inside or outside the body to replace or supplement physiological functions and to enhance the quality of diagnosis and care. Thus, biomedical engineering refers to the application of engineering techniques to problems in medicine and biology.

The interplay among the physical sciences, engineering, biology, and the medical sciences takes many forms. The traditional study of complex systems, whether for power transmission, communications, or the operation and control of industrial processes, has provided engineers with a number of concepts and techniques that proved valuable in analysis and design. These principles expressed in mathematical form are applicable to a wide range of phenomena, including those in biological processes. Information theory, statistics, and computer technology have opened new areas for exploration of sensory and central nervous activity as well as patient handling and diagnosis. Theories for feedback controls, transport processes, materials science, and mechanics provide new insight into homeostatic physiological processes. Analysis of heat transfer, fluid flow, and chemical-process control in living organisms requires competence in both engineering and the life sciences. Current studies help provide understanding of many physiological processes. This understanding, in turn, leads to improvements in clinical practice, diagnosis, and patient care.

Northwestern was among the first schools to recognize the value of a biomedical engineering background, and today the Department of Biomedical Engineering offers, at both the undergraduate and graduate levels, one of the largest and broadest programs in the country. The primary path students follow is the biomedical engineering program administered by the biomedical engineering department, but alternative biomedical options are offered in other engineering departments.

The biomedical engineering program provides biomedical training that is quantitative, emphasizes problem solving, and treats phenomena from the molecular to the systems levels. This curriculum prepares students for careers in dentistry, medicine, and/or research or with corporations in the health care industry. Required courses in mathematics, engineering, and science establish a strong foundation on which to build a biomedical framework. In addition, each student selects one sequence of courses with which to develop an area of specialization.

Students earning a biomedical engineering degree must obtain a minimum of 18 total course credits in engineering design and engineering science and have obtained substantial training in design.

Those seeking admission to dental or medical school should be familiar with the entrance requirements of those schools to which they intend to apply. In addition to the specifically required courses of the biomedical engineering program, many professional schools also require additional courses in physics, organic and/or physical chemistry, and laboratory biology. These requirements may be satisfied by judicious use of electives.

Tracks

Biological Materials and Molecular Engineering

This track combines biochemistry, materials science, molecular biology, and other research areas to generate devices and interfaces with functionality from the nanoscale to the microscale. Students learn to engineer technologies with translational relevance by integrating fundamental synthesis/fabrication principles with relevant medical needs.

Biomechanics and Rehabilitation
In this track, solid (e.g., musculoskeletal) and fluid (e.g., cardiovascular, pulmonary) mechanics are applied to human physiology in the design and manufacture of limb prostheses or artificial organs.

Biomedical Signals and Images
Imaging and signal processing have become integral parts of biomedical engineering. Applications of these disciplines include magnetic-resonance imaging (MRI), CT and PET scans, neural signal analysis, and optics. Students in this track obtain a solid foundation in mathematics, physics, and physiology with an emphasis on applications in image and signal analysis. This track is appropriate for students interested in pursuing a career in MRI, medical physics, biomedical optics, and neural engineering.

Electrical Engineering and Computer Engineering
Electronic instruments are widely used in the diagnosis and treatment of disease and in the study of normal physiological function. Students in this area learn the fundamentals of electronic and computer instrumentation (hardware and software) with specific focus on their applications in biomedicine.

Transport Processes and Tissue Engineering
This track concerns the application of engineering principles to the design, modulation, and/or replacement of cells, tissues, and organs. Students learn concepts of fluid mechanics, mass transfer, and the molecular and cellular biology necessary in this area.

Degree in Biomedical Engineering

Requirements (48 units)

Core courses (32 units)
See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses: PHYSICS 135-2,3; CHEM 102 and 103 *or* 171 and 172
- 3 design and communications courses
- 5 basic engineering courses
  - *Fluids and solids:* BMD ENG 270 and 271
  - *Materials science and engineering:* MAT SCI 201 or 301
  - *Probability, statistics, and quality control:* 1 course from BMD ENG 220; IEMS 201, 303; MECH ENG 359
  - *Thermodynamics:* 1 course from BMD ENG 250; CHEM 342-1; MECH ENG 220
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- BMD ENG 101 (noncredit)
- 9 core courses: BIOL SCI 210-2; CHEM 210-1; BMD ENG 301, 302, 303, 305, 306, 307, 390-1
- 7 courses in an area of specialization
  - 5 courses selected from one of the following tracks or an alternate set of courses developed with their advisers and approved by the Biomedical Engineering Undergraduate Committee:
    - *Biological materials and molecular engineering*
    - *Biomechanics and rehabilitation*
    - *Biomedical signals and images*
    - *Computer engineering*
    - *Electrical engineering*
    - *Transport processes and tissue engineering*
  - 2 technical electives – May include BIOL SCI 210-1,3; CHEM 101, 210-2; EECS 230; and any courses in engineering, science, or mathematics at the 300 level or higher. – Students are urged to choose technical electives that emphasize engineering design.
- Courses in the major program must be at the 200 level or higher; none may be taken P/N.

Courses

BMD ENG 101-0 Introduction to Biomedical Engineering
(0 units) Faculty, students, and guests present various topics introducing the field of biomedical engineering: different tracks within the program of study, possible career and research opportunities, and ethics.

BMD ENG 220-0 Introduction to Biomedical Statistics
Basic statistical concepts presented with emphasis on their relevance to biological and medical investigations.

BMD ENG 250-0 Thermodynamics Physical and chemical principles as applied to biological systems and medical devices. Topics include material balances, thermodynamics, solution chemistry, electrochemistry, surface chemistry, transport, and kinetics. Prerequisites: MATH 230; CHEM 103 or 172.

BMD ENG 270-0 Fluid Mechanics Fundamentals of fluid mechanics and their applications to biological systems. Prerequisites: GEN ENG 205-4; MATH 234.

BMD ENG 271-0 Introduction to Biomechanics Analysis of stresses and deformations in solids. Problems in biomechanics, with particular emphasis on assumptions appropriate to modeling biological materials including bone, skin, muscle, and cell membranes. Prerequisite: GEN ENG 205-2.

BMD ENG 301-0 Systems Physiology Functional/structural aspects of mammalian nervous system. Neural biophysics. Laboratory exercises. Prerequisites: PHYSICS 135-2; junior standing.

BMD ENG 302-0 Systems Physiology Cardiovascular and respiratory physiology. Human physiology from a quantitative viewpoint. Anatomy and pathology, where appropriate. Prerequisite: MATH 230.

BMD ENG 303-0 Systems Physiology Cellular mechanisms of and quantitative systems approach to human renal, digestive, endocrine, and metabolic physiology. Prerequisite: BIOL SCI 210-2; junior standing recommended.

BMD ENG 305-0 Biomedical Signal Analysis Introduction to biomedical signals and systems. Time and frequency domain analysis: convolution representation, Fourier series, Fourier transforms, frequency response, filtering, sampling. Prerequisite: PHYSICS 135-2 or consent of instructor.

BMD ENG 306-0 Biomedical Systems Analysis Introduction to linear systems analysis. Time and frequency domain techniques for analyzing linear systems, emphasizing their applications to biomedical systems. Matlab-based problem sets and lab illustrate topics covered in class. Prerequisites: GEN ENG 205-4; BMD ENG 305.

BMD ENG 307-0 Quantitative Experimentation and Design Laboratory and associated lecture concerning quantitative physiology, physiological measurement techniques, instrument design, and statistical design of experiments. Prerequisites: 305, 306, and one of the following: 220; IEMS 201, 303; MECH ENG 359.

BMD ENG 310-0 Molecular and Cellular Aspects of Bioengineering Molecular/cellular structure and function, mechanical influences on biological systems, molecular/cellular experiments. Prerequisites: BIOL SCI 210-2; GEN ENG 205-3.

BMD ENG 314-0 Models of Biochemistry and Molecular Biology Mathematical modeling of biochemical and molecular biological problems, such as allosteric enzymes, bacterial transduction, X-ray diffraction, study of DNA. Prerequisite: junior standing recommended.

BMD ENG 315-0 Application of Genetic Engineering to Immunochemistry Recent developments in genetic engineering as applied to the rapidly developing field of immunochemistry for antibodies and related proteins. Prerequisite: junior standing recommended.

BMD ENG 317-0 Biochemical Sensors Theory, design, and applications of chemical sensors used in medical diagnosis and patient monitoring. Electrochemical and optical sensors. Prerequisites: BIOL SCI 210-2; CHEM 210-1; PHYSICS 135-2,3.

BMD ENG 323-0 Visual Science Mammalian visual system. Optics of the eye. Visual image representation and interpretation. Visual adaptation. Motion. Color vision. Prerequisite: PHYSICS 135-2.

BMD ENG 325-0 Introduction to Medical Imaging Diagnostic X rays; X-ray film and radiographic image; computed tomography; ultrasound. Prerequisites: PHYSICS 135-3 or equivalent.

BMD ENG 327-0 Magnetic Resonance Imaging Nuclear magnetic resonance; two-dimensional Fourier transform, spin-echo and gradient-echo imaging; gradient and RF hardware. Prerequisites: PHYSICS 135-3.

BMD ENG 333-0 Modern Optical Microscopy and Imaging Rigorous introduction to principles, current trends, emerging technologies, and biomedical applications of modern optical microscopy.

BMD ENG 343-0 Biomaterials and Medical Devices Structure-property relationships for biomaterials. Metal, ceramic, and polymeric implant materials and their implant applications. Interactions of materials with the body. Prerequisites: MAT SCI 201 or 301; senior standing.

BMD ENG 344-0 Biological Performance of Materials Structure-property relationships of materials, physical chemistry of surfaces and interfaces, materials-tissue interactions, applications to the selection and design of materials for medical implants and devices. Prerequisite: MAT SCI 201.

BMD ENG 346-0 Tissue Engineering In vivo molecular, cellular, and organ engineering, with an emphasis on the foundations, techniques, experiments, and clinical applications of tissue engineering. Prerequisites: BIOL SCI 210-2 or CHEM ENG 375; GEN ENG 205-3.

BMD ENG 349-0 Bioregenerative Engineering Fundamentals, mechanisms, and clinical significance of biological regeneration and application of engineering principles to regenerative medicine. Prerequisite: BIOL SCI 210-2.

BMD ENG 350-0 Mass and Heat Transport Fundamental and biomedical applications of diffusive and convective heat and mass transfer. Prerequisites: 270; MATH 230; BMD ENG 377 recommended.

BMD ENG 359-0 Regenerative Engineering Laboratory Principles and technologies for developing regenerative therapies. Fundamental labs in molecular, cellular, and tissue regenerative engineering. Prerequisites: BIOL SCI 210-2 and BMD ENG 349; may be taken concurrently with BMD ENG 349.

BMD ENG 365-0 Control of Human Limbs and Their Artificial Replacements Human movement, biomechanics, skeletal and muscular anatomy, comparative anatomy, muscle physiology, and locomotion. Engineering design of artificial limbs. Prerequisite: senior standing with engineering or physical science background.

BMD ENG 366-0 Biomechanics of Movement Engineering mechanics applied to analyze human movement, including models of muscle and tendon, kinematics of joints, and dynamics of multijoint movement. Applications in sports, rehabilitation, and orthopedics. Prerequisite: MECH ENG 202, BMD ENG 271, or consent of instructor.

BMD ENG 371-0 Mechanics of Biological Tissues Stress and strain for small and large deformations. Nonlinear elastic, viscoelastic, pseudoelastic, and biphasic models. Prerequisites: GEN ENG 205-1,2; BMD ENG 271.

CHEM ENG 371-0 Transport Phenomena in Living Systems See Chemical Engineering.

BMD ENG 377-0 Intermediate Fluid Mechanics Fundamental concepts of fluid dynamics. Kinematics, mass and momentum balances, constitutive relations.

Navier-Stokes equations and methods of solution. Sealing techniques. Prerequisite: 270 or consent of instructor.

BMD ENG 383-0 Cardiovascular Instrumentation Theory, design, and application of instrumentation used for diagnosis, monitoring, treatment, and research investigation of cardiac and cardiovascular diseases. Examples from the current literature. Prerequisite: EECS 202, 270, equivalent, or consent of instructor.

BMD ENG 388-0-SA Health care Technology in Resource-Poor Environments Introduction to health systems in the context of disease burden, with special emphasis on developing countries and the devices and drugs used to combat diseases there. Restricted to students in Northwestern's Public Health in South Africa study abroad program. Prerequisite: consent of instructor.

BMD ENG 389-0-SA Health care Assessment and Planning Introduction to formal concepts and methodologies used in health-technology planning, assessment, and adoption for cost-effective health care delivery. Restricted to students in Northwestern's Public Health in South Africa study abroad program. Prerequisite: consent of instructor.

BMD ENG 391-0-SA Health care Technology Innovation and Design Principles and practice of medical device design for the developing world. Evaluation of user needs in the environment of underresourced segments of the South African health care system. Restricted to students in Northwestern's Public Health in South Africa study abroad program. Prerequisite: consent of instructor.

BMD ENG 390-1,2 Biomedical Engineering Design 1. Open-ended team-designed projects in the medical devices arena. Systems approach requiring design strategy and concepts, including reliability, safety, ethics, economic analysis, marketing, FDA regulations, and patents. Written and oral reports. Prerequisite: 307. **2.** Development of a design project initiated during the previous quarter. Prerequisite: 390-1.

BMD ENG 395-0 Special Topics in Biomedical Engineering

BMD ENG 399-0 Projects Must be taken P/N.

CHEMICAL ENGINEERING

www.chem-biol-eng.northwestern.edu

Chemical engineering is concerned primarily with the principles and processes involved in the conversion of raw materials into products vital to modern civilization. The products of the chemical and process industries range from antibiotics to zirconium, from petroleum to pharmaceuticals, from agricultural chemicals to plastics and synthetic rubber. The rapid introduction of new products by the chemical and bioprocess industries gives chemical engineering its characteristic concern with the management and development of innovation. Preparation for careers in chemical engineering requires a comprehension of physical, chemical, biological, and engineering principles. The program aims at developing people who can plan, design, and operate new processes and who may have potential for managerial responsibility in highly technical industrial enterprises.

The chemical engineering curriculum provides this broad fundamental training and prepares graduates for the chemical and process industries or advanced study. The first two years are devoted largely to mathematics, physics, chemistry, and basic engineering. After this, the fundamentals of chemical engineering fall into two sequences: the chemical process principles, emphasizing thermodynamics and kinetics of chemical change, and the transport processes, emphasizing the transfer of mass, momentum, and thermal energy in the physical handling of substances and in their heating, cooling, separation, and purification. Theoretical principles and practical applications are then integrated in courses in systems design and control. Supporting courses in allied fields of engineering and the sciences broaden the technical proficiency of chemical engineers, while courses in the social sciences, humanities, and arts deepens their background in the common hopes and problems of humanity.

Areas of Specialization

The curriculum permits students to select an area of specialization and to develop background for further study at the graduate level or for application to specific industries. Students are encouraged to select one of the six areas listed below or to plan an alternate program with an adviser. There are numerous electives in the basic program, and students are urged to give early consideration to planning for effective use of these opportunities.

Biomedical Engineering

Increasing numbers of chemical engineers enter medical school and work in related areas such as pharmaceutical production, biomedical materials, and artificial organs. The biomedical engineering option satisfies the needs of these students by adding courses in biology, biochemistry, and biomedical engineering to the foundation in chemical engineering. Students therefore can prepare for careers in medicine or biomedical engineering as they obtain a degree in chemical engineering.

Biotechnology

Biotechnology is the industrial exploitation of biological systems or processes. Microorganisms are employed for production of food, beverages, antibiotics, and solvents as well as for waste treatment. Advances in genetic engineering have led to the production (in animal cells, yeast, and bacteria) of a wide range of enzymes, growth factors, hormones, immunoregulators, and monoclonal antibodies for use in disease diagnosis and therapy. Animal cells and microorganisms produce chemicals via a complex network of tightly regulated chemical reactions, making biotechnology a natural extension of chemical engineering. The biotechnology option provides the background necessary to apply chemical engineering skills in biological systems, especially for process optimization, control, scale-up, and product recovery.

Chemical Process Engineering
The chemical process engineering option is designed to prepare students for many areas, including design, operations, research, and management. Recommended for students who want a broad background in chemical engineering, it provides preparation for employment in many fields, including the chemical process and petroleum industries. It is also good preparation for graduate work in chemical engineering or other areas, both technical and nontechnical.

Environmental Engineering
Means for improving the quality of our environment, disposing of wastes, and devising waste-free processes often involve chemical processing. The development, construction, and operation of these processes increasingly involves chemical engineers in a leading role. The next decade will see the replacement of many present industrial processes by new ones designed to eliminate or minimize waste products, requiring imaginative engineering. The environmental engineering specialization offers students a way to add special competence in environmental and civil engineering concerns to a chemical engineering degree and to prepare for attacking environmental problems.

Polymer Science and Engineering
Synthetic polymers are large molecular substances that now provide the basis for the plastics, fiber, and rubber industries. Synthetic polymers are used in fields as diverse as the automotive industry, pollution abatement, low-cost housing, and biomedical engineering and indeed wherever needs exist for new materials with unique properties.

The polymer field requires a knowledge of chemistry and some background in materials science in combination with expertise in chemical engineering, especially in transport processes. The option in polymer science and engineering provides training to undergraduates considering working in the field or going to graduate school. Chemical laboratory experience is also a part of the polymer course.

General Chemical Engineering
This option provides flexibility for students who desire exposure to a wide range of topics or who wish to specialize in fields of science or engineering not listed above.

Laboratories
The Undergraduate Chemical Engineering Laboratory provides facilities for exploring firsthand the quantitative experimental implications of fundamental laws in their application to practical problems of heat transfer, distillation, reaction engineering, and other basic operations. A computing laboratory is used in a variety of courses.

Degree in Chemical Engineering
Requirements (48 units)
Core courses (32 units)
See general requirements on page 198 for details.
- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses: PHYSICS 135-2,3; CHEM 102 and 103 *or* 171 and 172
- 3 design and communications courses
- 5 basic engineering courses
  - *Fluids and solids:* CHEM ENG 321
  - *Materials science and engineering:* MAT SCI 301
  - *Probability, statistics, and quality control:* CHEM ENG 312 or IEMS 303
  - *Systems engineering and analysis:* CHEM ENG 210
  - *Thermodynamics:* CHEM ENG 211
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)
- 11 required courses: CHEM 210-1,2; CHEM ENG 212, 275, 307, 322, 323, 341, 342, 351, 352 (BIOL SCI 210-2 may substitute for CHEM ENG 275)
- 5 technical electives
  - 2 advanced chemical engineering courses from an approved list available from the department
  - 3 engineering or advanced science or mathematics courses from approved lists available from the department

Minor in Biotechnology and Biochemical Engineering
This minor provides specific training for students interested in industries that create and manufacture pharmaceuticals, biomaterials, and agents for gene and cell therapies or for those desiring in-depth preparation for future graduate study in biotech research.

Requirements (10 units)
- 5 courses in biological science and biochemical engineering: BIOL SCI 210-1, 210-3; BIOL SCI 210-2 or CHEM ENG 275; CHEM ENG 375, 377
- 1 quarter of research (CHEM ENG 399) in an approved laboratory; students should verify with the minor coordinator that the project and lab are appropriate
- 4 electives providing opportunity for greater depth in both fundamental biology and engineering applications:
  - 1 course from CHEM ENG 371, 372, 379, 475, 478, 479
  - 1 course from BIOL SCI 301, 309, 315, 319, 323, 333, 355, 390

    - 2 additional courses from the lists above or from BMD ENG 315, 317, CHEM 210-3, CIV ENV 441, or up to 2 more units of CHEM ENG 399
- A minimum GPA of 2.0 is required in the courses in the certificate program.
- A McCormick BS degree must be completed.
- No more than 5 courses may be double-counted to fulfill requirements in the major program.
- Students should discuss how best to satisfy prerequisites for required courses, especially CHEM ENG 375, with the minor coordinator.
- Students must complete a "Petition to Receive" form for the minor and submit it to the McCormick Academic Services Office before the beginning of their final quarter as undergraduates.

Courses

CHEM ENG 190-0 Engineering of Chemical and Biological Processes Survey of engineering principles as they are applied to processes involving chemical and biological transformations. Examples from the chemical, pharmaceutical, biotechnology, food processing, electronics, and other industries. Impact of economics, ethics, and other nontechnical constraints.

CHEM ENG 210-0 Analysis of Chemical Process Systems Introduction to process systems. Material balances and stoichiometry. Analysis of process system flow sheets. Introduction to departmental computing facilities. Basic numerical analysis. Prerequisites: CHEM 103; GEN ENG 205-4 (may be taken concurrently).

CHEM ENG 211-0 Thermodynamics The first and second laws of thermodynamics. Entropy and equilibrium. Material and energy balances. Equations of state and properties of fluids. Solutions, phase equilibria, and chemical reactions. Prerequisite: 210.

CHEM ENG 212-0 Phase Equilibrium and Staged Separations Thermodynamic models of mixtures and phase equilibrium. Analysis and design of staged separation processes such as distillation, absorption, stripping, and extraction. Prerequisite: 210, 211.

CHEM ENG 275-0 Molecular and Cell Biology for Engineers Introduction to cell and molecular biology concepts that provide the foundation for modern biotechnology and bioengineering. Prerequisite: CHEM 103.

CHEM ENG 307-0 Kinetics and Reactor Engineering Chemical reaction kinetics with application to the design of chemical reactors. Prerequisites: 210, 211, 321, 322.

CHEM ENG 312-0 Probability and Statistics for Chemical Engineering Introduction to probability theory and statistical methods necessary for analyzing the behavior of processes and experiments. Statistical tests for detecting significant changes in process parameters. Prerequisite: MATH 220, 224, 230, 234, or equivalent.

CHEM ENG 321-0 Fluid Mechanics Derivation and applications of continuity and Navier-Stokes equations. Macroscopic mass, momentum, and energy balance. Dimensional analysis: friction factors in pipes and packed beds; drag coefficients. Prerequisites: completion of mathematics requirements with no grades of D; GEN ENG 205-4 (C– or better).

CHEM ENG 322-0 Heat Transfer The differential equations of energy transport. Solutions for various applications. Prerequisite: completion of mathematics requirements with no grades of D; GEN ENG 205-4 (C– or better); CHEM ENG 321 recommended.

CHEM ENG 323-0 Mass Transfer Diffusion and rate concepts; application to distillation, extraction, absorption, humidification, drying. Prerequisites: 321, 322.

CHEM ENG 341-0 Dynamics and Control of Chemical and Biological Processes Dynamic behavior of chemical process components. Feedback control principles. Prerequisite: senior standing; 307.

CHEM ENG 342-0 Chemical Engineering Laboratory Operation and control of process equipment for the determination of operating data. Analysis and written presentation of results. Prerequisites: 212, 307, 321, 322, 323.

CHEM ENG 345-0 Process Optimization Modern techniques and application to the design and operation of chemical process systems. Steady-state and dynamic methods. Experimental search for the optimum. Prerequisite: junior standing.

CHEM ENG 351-0 Process Economics, Design, and Evaluation Preliminary design of industrial processes for the production of chemical and allied products by the application of the engineering sciences and economics. Prerequisites: 212, 307, 321, 322, 323.

CHEM ENG 352-0 Chemical Engineering Design Projects Design of chemical and process plants applying the principles of unit operations, thermodynamics, reaction kinetics, and economics. Mechanical design and selection of chemical process equipment. Prerequisite: 351.

CHEM ENG 361-0 Introduction to Polymers Polymerization mechanisms and their relation to molecular structure, polymerization processes, and the mechanical properties of polymers, especially flow behavior. Prerequisites: 211 or other thermodynamics course; CHEM 210-1.

CHEM ENG 364-0 Chemical Processing and the Environment Application of chemical engineering fundamentals to environmental problems. Chemistry and mechanisms, chemical reaction and rate, and transport emphasized. Risk assessment and analysis revealed through case studies. Prerequisites: 212, 307.

CHEM ENG 365-0 Sustainability, Technology, and Society Technical discussion of sustainability, sustainable development, global warming, natural and renewal resources and utilization, industrial ecology, ecoefficiency, technology related to sustainability, and risk assessment. Prerequisite: junior standing in science or engineering.

CHEM ENG 371-0 Transport Phenomena in Living Systems Application of transport theory, principally diffusion, to movement of molecules in biological systems, including blood, cornea, microcirculation, and lung. Prerequisites: 275 or BIOL SCI 210-2; 321, 323, BMD ENG 270, or equivalent; or consent of instructor.

CHEM ENG 372-0 Interfacial Phenomena and Bionanotechnology The physical chemistry of systems of large interfacial area, with specific examples of their unusual behavior and useful properties for applications in bionanotechnology. Prerequisite: senior standing or consent of instructor.

CHEM ENG 375-0 Biochemical Engineering Modern biochemical engineering. Life sciences: microbiology, biochemistry, and molecular genetics. Metabolic stoichiometry, energetics, growth kinetics, transport phenomena in bioreactors, and product recovery. Prerequisite: 307, 323, or consent of instructor.

CHEM ENG 377-0 Bioseparations Downstream process in biotechnology. Separation and lysis of cells. Recovery of organelles and proteins. Protein separation and purification. Prerequisite: 323 (may be taken concurrently); 275 or BIOL SCI 210-2.

CHEM ENG 379-0 Computational Biology: Principles and Applications Introduction to the development and application of data-analytical and theoretical methods, mathematical modeling, and computational simulation techniques to the study of biological systems.

CHEM ENG 390-0 Personal and Organizational Effectiveness Introduction to nontechnical skills required in a business environment, with the goal of increasing personal effectiveness and marketability of seniors and graduate students. Prerequisite: senior standing.

CHEM ENG 395-0 Special Topics in Chemical Engineering Topics suggested by students or faculty and approved by the department.

CHEM ENG 396-0 Focused Topics in Chemical Engineering (.5 unit) Emerging topics suggested by students or faculty and approved by the department.

CHEM ENG 399-0 Projects Supervised investigation of a chemical engineering problem with submission of a final report.

CIVIL AND ENVIRONMENTAL ENGINEERING

www.civil.northwestern.edu

The Department of Civil and Environmental Engineering offers two degree programs for undergraduate students, one in civil engineering and another in environmental engineering. Civil and environmental engineers play central roles in defining sustainable development approaches to the interactions of humans with earth systems. These programs place strong emphasis on design, communication, teamwork, and the development of a systems perspective on the complex problems of today and tomorrow.

Civil Engineering

Civil engineers plan systems such as transportation networks or procedures for water control and supply, and they design structures such as buildings, bridges, dams, and sewage disposal plants. They work together with ecologists, sociologists, economists, lawyers, and others to plan how to wisely use the human and natural resources of large areas such as river basins and how to redevelop cities. With few exceptions, each planning or design job is one of a kind, as contrasted with more routine solutions to other engineering problems.

Planning, of course, requires abundant data of all sorts—topography, geology, soils, vegetation, weather and climate, stream-flow and lake currents, traffic routes and patterns, pollution, population, cultural background and preferences, skills and ambitions. Many civil engineers collect, analyze, and present the data, developing and improving measuring instruments as part of their job. Others apply probability and statistical methods to the data to forecast such things as population growth, demand for water and transportation, maximum winds and precipitation, height of floods, and air and water quality.

Designing systems and structures requires the planning forecasts plus accurate data on the mechanical properties of materials such as steel, concrete, soils, rocks, and plastics and on the behavior of structural components made from them. Some civil engineers test materials and physical models to obtain such data. Many more use known physical properties and the laws of mechanics—energy, momentum, and conservation of mass—to design structures, foundations, pavements, pipe networks, and treatment plants that will do the job safely and economically.

Civil engineers who design water and waste treatment facilities or set up programs to reduce air and water pollution need to understand certain chemical reactions and biological processes as well as the usual fluid and solid mechanics. Engineers who help to plan and design a system understand how and why it works and what may go wrong with it. Hence, civil engineers may operate treatment facilities or systems of flood control reservoirs or set up and administer traffic control plans. Civil engineers may become city engineers.

Engineers who design structures and know soil mechanics learn the practical difficulties of providing a foundation and erecting the structure. Thus, they become partly qualified to operate construction companies, with some entering the construction business. Administrative and business activities require them also to learn something about accounting, personnel management, and contracts.

Since civil engineering students have such a wide range of career options, the Department of Civil and Environmental Engineering prescribes a minimum of required courses and required subjects. Students elect the remainder freely or from specified broad categories. For details see the civil engineering curriculum.

Areas of Specialization

Civil engineering students may select a program that fits their needs by choosing courses judiciously. Students are encouraged to discuss with faculty any proposed program that meets a well-defined goal. Examples of courses selected in the areas of specialization most often pursued by students are listed in the civil engineering curriculum.

Degree in Civil Engineering

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses: PHYSICS 135-2; CHEM 101, 102; 1 course in astronomy, biological sciences, or earth and planetary sciences
- 3 design and communications courses
- 5 basic engineering courses
  - *Electrical science:* MECH ENG 233 or EECS 202 or 270
  - *Fluids and solids:* CIV ENV 216; MECH ENG 241
  - *Thermodynamics:* MECH ENG 220 or CHEM 342-1
  - 1 course from materials science and engineering, systems engineering and analysis, computer architecture and numerical methods, or computer programming
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 7 basic civil engineering courses: CIV ENV 221, 250, 260, 325, 330, 340; 371 or 376
- 2 mathematical techniques and science courses from an approved list, 1 of which must be a calculus-based probability and statistics course
- 5 technical electives at the 200 level or higher in mathematics, science, engineering, or another area supporting their area of specialization
- 2 courses from an approved list of design and synthesis courses; 1 must be CIV ENV 382, which may not be taken P/N
- 10 of the 16 courses in the major program must be civil engineering courses
- Listed are samples of some traditional areas of specialization, but students are encouraged to design with their advisers a program that meets their own particular interests.
  - *Mechanics of materials and solids*
  - *Construction*
  - *Environmental engineering*
  - *Geotechnical engineering*
  - *Structural engineering*
  - *Transportation systems*

Environmental Engineering

Environmental engineering is concerned with the interactions of people and environment, the applications of scientific knowledge to the understanding and analyses of these interactions, and the improvement of the quality of our environment.

Traditionally, environmental engineers have provided safe drinking water, treated and properly disposed of wastes, maintained air quality, controlled water pollution, and remediated sites contaminated by hazardous substances. They continue to do so, but with the realization that anthropogenic activities at the earth surface are modifying the natural environment at an accelerating pace.

Environmental engineers have become more concerned with the state of the environment. They also understand how complex environmental systems work. For example, they are developing molecular tools and new technologies to track and remove contaminates present at very low levels, and they are using genomic approaches to characterize microbial communities.

Environmental engineers have become a vital link between scientific discovery, technological development, and the societal need for protecting the health of humans and ecological systems. The emphasis is shifting from managing wastes to designing sustainable practices that foster recovery, recycling, and reuse of resources.

The environmental engineering curriculum provides a broad, fundamental training and prepares graduates for highly interdisciplinary work. The first two years are devoted largely to mathematics, physics, chemistry, basic engineering, and gateway courses that provide an overall view of earth systems. Subsequently, the fundamentals of environmental engineering and their application to the atmosphere, land, and the hydrosphere are emphasized.

This program provides an engineering and scientific basis for understanding contemporary environmental problems and approaches to their solutions, understanding the natural systems with which human activities must be compatible, and developing the engineering analysis and design tools necessary to plan and design environmental control systems. Completion of the undergraduate degree program in environmental engineering prepares students to practice engineering at the entry level or to continue their education at the graduate level. It serves as preparation for the Fundamentals of Engineering (FE) examination and, with adequate experience, the Professional Engineer (PE) examination.

Degree in Environmental Engineering

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses

- 4 basic science courses: PHYSICS 135-2; CHEM 101, 102, 103
- 3 design and communications courses
- 5 basic engineering courses:
  - *Systems engineering and analysis:* CIV ENV 304 or IEMS 326
  - *Thermodynamics:* BMD ENG 250; CHEM ENG 211; MAT SCI 314
  - *Fluids and solids:* MECH ENG 241
  - *Probability, statistics, and quality control:* 1 course from BMD ENG 220; CHEM ENG 312; CIV ENV 306 (recommended); EECS 302; IEMS 303; MECH ENG 359
  - 1 course from EECS 328; MAT SCI 201, 203, 301
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)
- 12 core courses: CHEM 210-1; CIV ENV 201, 202, 203, 260, 340, 361, 363, 364, 365, 367, 382
- 4 technical electives at the 200 level or higher in engineering, mathematics, or science, 3 of which must be engineering courses, and 2 of which must be from an approved list

Courses

CIV ENV 201-0 Earth: A Habitable Planet Chemical and physical perspectives on the evolution of the planet; the emergence of life and the nature of biogeochemical cycles; the role of human activities that are now part of these cycles. Prerequisites: MATH 224 or equivalent; CHEM 103, 172, or equivalent.

CIV ENV 202-0 The Health of the Biosphere Population processes in nature; role of human population growth; interactions between populations; major impacts of human populations on the environment. Prerequisite: MATH 224 or equivalent.

CIV ENV 203-0 Energy and the Environment: The Automobile Integrated study of fundamental chemistry, industrial production, energy use, and public policy using the automobile as an example. Prerequisites: MATH 224 or equivalent; CHEM 103, 172, or equivalent.

CIV ENV 216-0 Mechanics of Materials I Analytical and experimental study of stresses and deformations and their application to the design of machine and structural elements subjected to static, dynamic, and repeated loads. Prerequisite: 212 or GEN ENG 205-2.

GEN ENG 220-1,2 Analytical and Computer Graphics (.5 unit each) See General Engineering Courses.

CIV ENV 221-0 Theory of Structures I Deflections of structures, energy concepts, idealization of structures, truss analysis, column stability, and influence lines. Introduction to indeterminate truss and frame analyses, slope-deflection analysis, and moment distribution. Portal method. Prerequisite: 216.

MECH ENG 241-0 Fluid Mechanics I See Mechanical Engineering.

CIV ENV 250-0 Introductory Soil Mechanics Fundamental properties and behavior of soils as engineering materials. Origin of soils through the properties of soil components to the strength, permeability, and deformation of soil masses. Prerequisite: 216.

CIV ENV 260-0 Fundamentals of Environmental Engineering Mass and energy concepts applied to major issues facing environmental engineers: safe drinking water, surface water quality, ambient air quality, global atmosphere, managing solid and hazardous wastes. Prerequisites: CHEM 101; MATH 224 (may be taken concurrently).

CIV ENV 302-0 Engineering Law The American legal system from an engineer's perspective. Socratic-method analysis of statutory and case law. Contract, patent, corporation, antitrust, property, and environmental law. Torts, product liability, and arbitration. Prerequisite: junior standing.

CIV ENV 303-0 Environmental Law and Policy An introduction to important aspects of environmental law and policy. A wide range of environmental topics are covered, with a focus on national environmental policy as implemented through major federal environmental statutes. Prerequisite: junior or senior standing.

CIV ENV 304-0 Civil and Environmental Engineering Systems Analysis Quantitative techniques to develop descriptive and prescriptive models that support efficient planning and management of civil and environmental engineering systems. Prerequisite: MATH 224 or equivalent.

CIV ENV 306-0 Uncertainty Analysis in Civil Engineering Probability, statistics, and decision theory. Discrete and continuous random variables, marginal and conditional distributions, moments, statistical model selection and significance tests, hypothesis testing, and elementary Bayesian decision theory. Application to problems in soil mechanics, water resources, transportation, and structures.

CIV ENV 314-0 Organic Geochemistry The sources and fates of organic matter in the natural environment; global cycling of organic carbon; applications to the study of modern and ancient environments. Prerequisites: 1 course in earth and planetary sciences or environmental sciences and 1 course in chemistry.

CIV ENV 319-0 Theory of Structures II Shear center, nonprismatic members, nonlinear materials, influence lines, Mueller-Breslau principle, approximate methods of analysis, energy methods, stiffness matrix, and computer methods of analysis. Prerequisite: 221.

CIV ENV 320-0 Structural Analysis—Dynamics Single and multiple degree-of-freedom systems subjected to periodic, seismic, and general loadings. Time-history analysis of linear and nonlinear systems. Design methods for earthquakes. Prerequisite: 221.

CIV ENV 321-0 Properties of Concrete Concrete as a composite material; relationship between constitutive laws and microstructure; failure theories; fracture; fatigue; strain rate effects; destructive and nondestructive testing; creep and shrinkage; chemistry of cement hydration; admixtures; aggregates; proportioning; new materials.

CIV ENV 322-0 Structural Design Design criteria; planning and design aspects of structural systems for gravity and lateral loads. A total design project involving the analysis and design of a structure. Prerequisite: 222 or equivalent.

CIV ENV 323-0 Structural Steel Design Rational basis of structural design. Design approach for structural-steel components of a building system. Prerequisites: 216 and 221 or equivalent.

CIV ENV 325-0 Reinforced Concrete Fundamentals of reinforced concrete theory and design. Analysis and design of beams, slabs, and columns. Concurrent familiarization with current building codes, specifications, and practices. Prerequisite: 221.

CIV ENV 327-0 Finite Element Methods in Mechanics Development of finite elements from variational principles and application to static stress analysis. Introduction to techniques for transient and generalized field problems. Computer implementation of finite element techniques.

CIV ENV 330-0 Construction Management Techniques for coordinating decisions and actions of various parties in the design and construction of civil and environmental engineering projects. Delivery systems; preconstruction services; project planning; cost control and value engineering; bidding. Prerequisite: consent of instructor.

CIV ENV 332-0 Building Construction Estimating Estimation of cost at different stages of design; conceptual estimating, quantity takeoff of various elements, such as materials, labor, equipment. Prerequisite: 330 and consent of instructor.

CIV ENV 336-0 Project Scheduling Project planning, scheduling, and control using CPM arrow and precedence networks; basic resource allocation and leveling; earned-value analysis; linear scheduling; PERT charts; hands-on experience in using computer tools. Prerequisite: 330 or consent of instructor.

CIV ENV 340-0 Fluid Mechanics II Civil engineering applications of fluid mechanics. Turbulent flow in pipes, pipe networks, and open channels. Prerequisite: CHEM ENG 321; MECH ENG 241; or consent of instructor.

CIV ENV 346-0 Meteorology and Hydrology Mechanics of the atmosphere. Precipitation, runoff, groundwater flow. Methods of analyzing rainfall and stream-flow records for power generation, flood control, and water supply. Prerequisite: MECH ENG 241.

CIV ENV 349-0 Environmental Management The roles and responsibilities of project managers who deal with environmental issues. How managers deal with previously created environmental problems, respond to current requirements, and anticipate future needs. Prerequisites: a technical background and senior standing.

CIV ENV 352-0 Foundation Engineering Application of soil mechanics to analysis and design of foundations and embankments. Settlement of structures, bearing capacities of shallow and deep foundations, earth pressures on retaining structures, and slope stability. Prerequisite: 250.

CIV ENV 355-0 Engineering Aspects of Groundwater Flow Applied aspects of groundwater flow and seepage, including Darcy's law, parameter determination, aquifer test analysis, flow-net construction and application, modeling techniques, slope stability analysis, drainage, and filter design. Prerequisite: fluid mechanics.

CIV ENV 358-0 Airphoto Interpretation Principles and practice of using aerial photographs to obtain information about natural features of the earth's surface, with emphasis on earth materials. Landforms, geological processes, rocks, and soils. Stereoscopic photographs, elements of photogrammetry. Prerequisite: junior standing or consent of instructor.

CIV ENV 361-1 Environmental Microbiology Basic principles and practical applications of microbiology to environmental issues, such as microbial contamination, degradation of organic contaminants, production of alternative fuels, and global climate change.

CIV ENV 361-2 Public and Environmental Health Current problems in public and environmental health, such as the worldwide burden of major infectious diseases, emergence of new pathogens, and environmental reservoirs of infectious organisms. Prerequisite: 361-1 or consent of instructor.

CIV ENV 363-0 Environmental Engineering Applications I: Air and Land Nature and control of community air pollution. Sources, physical and chemical properties, and effects of major air pollutants; analytical measurements and monitoring of air pollutants; engineering and legislative control. Prerequisite: junior standing.

CIV ENV 364-0 Environmental Engineering Applications II: Water Engineering elements of water supply and water pollution abatement. Water quality standards, water and wastewater treatment processes, and the management of receiving waters to control pollution. Prerequisite: MECH ENG 241; CIV ENV 340 recommended.

CIV ENV 365-0 Environmental Laboratory Chemical and microbiological aspects of environmental engineering and science are explored through an integrated laboratory course.

CIV ENV 367-0 Aquatic Chemistry Terrestrial, freshwater, marine, and estuarine chemical equilibria in natural waters. Development of theoretical basis for the investigation of chemical behavior of aquatic systems emphasizing a problem-solving approach. Prerequisite: BMD ENG 250.

CIV ENV 368-0 Sustainability: Issues and Action, Near and Far Exploration of the issues that motivate the design and engineering of sustainable resource use and development.

CIV ENV 371-0 Introduction to Transportation Planning and Analysis Analysis and design of solutions to transportation problems; introduction to selected operations research and statistical analysis techniques; use of case studies in urban transportation, intercity passenger transport, and freight movements. Prerequisite: junior standing or consent of instructor.

CIV ENV 376-0 Transportation System Operations Traffic-flow theory; vehicle and human factors, capacity analysis, intersection performance and control; management and control of arterial streets and networks; neighborhood traffic restraint, urban transit operations. Operations concepts and theories applied to actual problems through laboratory practice. Prerequisite: basic understanding of calculus and statistics; knowledge of MATLAB is desirable but not required.

CIV ENV 382-0 Capstone Design Culminating team-based design experience in civil and environmental engineering, with an overview of the function, design, and operation of modern infrastructure systems. Prerequisite: senior standing in civil or environmental engineering or consent of instructor.

CIV ENV 385-1,2,3 Architectural Engineering and Design Architectural engineering and design studios: architectural history, case studies in design, construction and management of buildings, and drawing and model building. **1.** Fundamental studio: basic architectural and structural design of a simple building project. Prerequisite: junior standing in engineering or consent of instructor. **2.** Intermediate studio: architectural and structural design of a building project with multiple requirements. Prerequisites: junior standing in engineering; 385-1 or consent of instructor. **3.** Advanced studio: architectural and structural design of a large, complex building project. Prerequisite: junior standing in engineering; 385-2 or consent of instructor.

CIV ENV 395-0 Special Topics in Civil Engineering Topics suggested by students or faculty and approved by the department.

CIV ENV 398-1,2 Community-Based Design Yearlong participation in two- or three-person team projects involving research, analysis, and/or design in the solution of environmental problems affecting primarily lower-income communities. Grade assigned only on completion of both units. Prerequisite: consent of instructor.

CIV ENV 399-0 Projects Special studies under faculty direction. Credit to be arranged.

COMPUTER ENGINEERING

See Electrical Engineering and Computer Science.

COMPUTER SCIENCE

See Electrical Engineering and Computer Science.

See the Cross-School Options chapter for opportunities open to all Northwestern undergraduates.

DESIGN ENGINEERING

See Manufacturing and Design Engineering for the certificate in design engineering.

ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

www.eecs.northwestern.edu

The Department of Electrical Engineering and Computer Science offers three programs for undergraduate students leading to the bachelor of science degree: electrical engineering, computer engineering, and computer science. It also offers graduate programs leading to the MS and PhD degrees in those three areas. The department boasts an internationally renowned faculty, state-of-the-art research equipment, and the considerable resources offered by a great university. It combine these advantages with an uncommon commitment to students.

The department offers several interdisciplinary options, including premedical/biomedical studies and cognitive science. It collaborates with Weinberg College to offer that school's major in computer science (see page 78).

Detailed information on degree requirements and elective courses is available from the department office or at www.eecs.northwestern.edu.

Electrical Engineering

Electrical engineering involves the development and application of electronic and optical technologies for generating, communicating, and processing information. The electrical engineering curriculum includes courses in electronic circuits, solid-state electronics, electromagnetics, optics, lasers, controls, digital signal processing, communications and networks. Students may specialize in any of the following areas.

Circuits and Electronics

This area of study is concerned with the analysis and design of circuits that employ electronic devices, such as integrated circuits, transistors, diodes, light-emitting diodes, data storage elements, and image-forming devices. Important applications include AM and FM radio, television, digital computers, and electronic control instrumentation systems.

Communications Systems

A communication system involves the generation of an electrical signal representing information to be transmitted, its encoding in some form for efficient transmission, its actual transmission, its decoding at the receiving end of the system, and its reconversion into something intelligible to the user. The thorough study of communications systems theory requires knowledge of a broad range of mathematical methods and of the capabilities and limitations of electronic circuits. This subject also covers the design and analysis of communication networks for the transmission of audio, video, and data among many users.

Control Systems

The study of control systems deals with the analysis and design of automatic regulators, guidance systems, numerical control of machines, robotics, and computer control of industrial processes. Students are concerned with identifying these systems and with such topics as system stability, system performance criteria, and optimization. These concepts find application in other fields of engineering and in the development of better understanding of biological, energy, economic, and social systems.

Digital Signal Processing

Study in this area focuses on the digital representation and algorithmic manipulation of speech, audio, image, and video signals. Specific topics within this general area include image and video processing, recovery and compression, multimedia signal processing, filter design and rank-order operators, image and video transmission, medical and biomedical signal processing, medical imaging, and algorithms for medical instrumentation.

Electromagnetics and Photonics

Study in the area of photonic systems and technology focuses on microcavity lasers, nanostructures, quantum and nonlinear optics, integrated optics, fiber-optic and infrared waveguide devices, fiber-optic communications, computational electromagnetics, and imaging through turbulence. Special emphases include applications of novel quantum amplifiers in optical communications, imaging, and cryptography; devices for terabit second WDM and TDM optical networks; and applications of computational techniques in integrated and nonlinear optics.

Solid-State Engineering

This area is concerned with the design, physical principles, and applications of solid-state devices both as discrete units and integrated circuit systems. In addition to the various diode, transistor, and FET devices fabricated from silicon technology, other devices developed from compound semiconductor materials are reviewed. Both analog and digital circuit applications are stressed. Another important topic is the behavior of conductors in the superconducting state, with a stress on applications.

Degree in Electrical Engineering

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses
  - PHYSICS 135-2,3
  - 2 courses from
    - *Physics:* PHYSICS 335
    - *Biological sciences:* BIOL SCI 210-1, -2,-3; CHEM ENG 275
    - *Chemistry:* CHEM 101, 102, 103, 171, 172, 210-1,2
    - *Earth and planetary sciences/astronomy:* EARTH 201, 202; ASTRON 220
- 3 design and communications courses
- 5 basic engineering courses
  - EECS 202, 203, 302 (grade of C- or better in 202 and 203 required for graduation)
  - EECS 211 *or* 230
  - 1 course from BMD ENG 250, 270, 271; CHEM 342-1; CHEM ENG 210, 211, 321; CIV ENV 216, 219, 304; IEMS 310, 313, 326; MECH ENG 220, 241, 370; MAT SCI 201, 203, 301, 314, 315
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 5 required courses: EECS 221, 222, 223,224, 225
- 10 technical electives
  - at least 6 courses from the following six tracks:
    - *Biomedical engineering track:* BMD ENG 317, 325, 327, 333, 383
    - *Circuits and electronics track:* EECS 303, 346, 353, 355, 391, 393
    - *Communications systems track:* EECS 307, 333, 378, 380
    - *Control systems track:* EECS 360 *or* MECH ENG 391; EECS 374, 390; MECH ENG 333
    - *Digital signal processing track:* EECS 332, 359, 363
    - *Electromagnetics and optics track:* EECS 308, 379, 382, 383, 386
    - *Solid-state engineering track:* MECH ENG 381; EECS 250, 381, 384, 385, 388
  - 2 courses from 300-level EECS technical electives (which may include the courses above)
  - 2 courses may be chosen from BIOL 210-1,2,3; CHEM 210-1,2,3; or 300-level technical courses in science, mathematics, computer science, or engineering and may include the courses above.
  - No more than 2 units of 399 will be counted as technical electives. Additional units of 399 may be taken but will be counted as unrestricted electives.
- 1 required design course: 1 course from EECS 347-1, 392, 398, 399 (when 399 is a design project)

Computer Engineering

Computer engineering deals with digital design, computer hardware and architecture, robotics, microprocessors, software and programming, and the interrelationships between hardware and software. The computer engineering curriculum involves courses in digital logic, electronic circuits, computer architecture, robotics, VLSI design, VLSI CAD, software programming, operating systems, microprocessor systems, and parallel computing. The computer engineering curriculum allows students to develop a particular specialization in the following areas.

Embedded Systems
This area focuses on the use of digital hardware to monitor and control physical systems. Topics include discrete dynamics systems, digital controllers, analog-to-digital converters, microprocessor-based design, and the economic trade-offs of different software and hardware systems.

High-Performance Computing
This area introduces students to the field of state-of-the-art high-performance computing. In particular, it deals with aspects of computing involving multiple processors working together on a common problem, including issues of computer architecture, parallel programming and algorithms, numerical computing, and computer networking.

Software
This area exposes students to concepts and skills necessary to implement and understand computer software. Students are taught the techniques of designing and analyzing efficient algorithms, how to develop operating systems and compilers, and how to write programs using efficient data structures and software engineering practices.

VLSI and Computer-Aided Design
This area focuses on systematic approaches to designing high-performance integrated circuits consisting of millions of transistors. This specialization includes topics such as low-power, high-speed, and reliable circuit design, hardware-software codesign, design verification, design of field-programmable gate array (FPGA), and computer-aided design (CAD) techniques.

Degree in Computer Engineering

Requirements (48 units)

Core courses (32 units)
See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses
  - PHYSICS 135-2,3
  - 2 courses from ASTRON 220; BIOL SCI 210-1, -2, -3; CHEM 101, 102, 103, 171, 172, 210-1,2; CHEM ENG 275; EARTH 201, 202; PHYSICS 335
- 3 design and communications courses
- 5 basic engineering courses
  - *Computer architecture and numerical methods:* EECS 203 (grade of C– or better required for graduation)
  - *Computer programming:* EECS 211
  - *Electrical science:* EECS 202 (grade of C– or better required for graduation)
  - *Probability, statistics, and quality control:* EECS 302
  - 1 course from BMD ENG 250, 270, 271; CHEM 342-1; CHEM ENG 210, 211, 321; CIV ENV 216, 219, 304; IEMS 310, 313, 326; MAT SCI 201, 203, 301, 314, 315; MECH ENG 220, 241, 370
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 5 required courses: EECS 205, 221, 303, 311, 361
- 10 technical electives
  - at least 2 courses from EECS 213, 222, 223, 224, 225
  - 5 courses from the following four tracks:
    - *Embedded systems track:* EECS 332, 346, 347-1, -2, 390; BMD ENG 384
    - *High-performance computing track:* EECS 328, 333, 339, 350, 354, 358, 362, 452, 453
    - *Software track:* EECS 310, 322, 336, 339, 343, 394, 395 (by petition)
    - *VLSI and CAD track:* EECS 353, 355, 357, 391, 392, 393, 492, 459
  - 3 electives from BIOL 210-1,2,3; CHEM 210-1,2,3; or 300-level technical courses in science, mathematics, computer science, or engineering
  - No more than 2 units of 399 will be counted as technical electives. Additional units of 399 may be taken but will be counted as unrestricted electives.
- 1 required design course from EECS 347-1, 362, 392

Computer Science

Computer science involves the understanding, use, and extension of computational ideas and their implementation. A Northwestern computer science graduate will

- Comprehend the breadth of computer science, its key intellectual divisions and questions, and its past and likely future influence on engineering, science, medicine, business, and law
- Approach problems from the algorithmic perspective, understanding the nature and broad reach of computation and how to apply it abstractly
- Approach problems from the systems perspective, understanding the evolving layers of the software/hardware stack and how to create, use, and extend them
- Approach problems from the perspective of artificial intelligence, understanding how to make progress solving seemingly intractable problems
- Design and implement complex software systems, individually and as a team member
- Design and implement effective human-machine interfaces

Courses and undergraduate research opportunities focus on software, ranging from theoretical models to practical applications, and establish a common breadth of knowledge in computer science, allowing students flexibility in areas in which they choose to specialize, such as

- *Artificial intelligence*, including mobile robots with perceptual systems, models of memory and reasoning, knowledge representation, natural-language comprehension, planning, and problem solving
- *Computer systems*, including parallel, distributed, and real-time systems, performance evaluation, prediction, and scheduling
- *Networked systems*, including peer-to-peer computing, large-scale data storage, network security, and pervasive computing environments
- *Programming languages and compilers*, including semantics, optimization, and software
- *Human-computer interaction*, including interface design, task modeling, intelligent interfaces, and authoring tools
- *Distributed interactive systems*, including client-server and web-based applications, such as heterogeneous databases and multimedia learning environments
- *Theoretical computer science*, focusing on algorithm design and analysis of algorithms' worst- and average-case behavior
- *Intelligent information systems*, including "frictionless" proactive systems and context- and task-sensitive retrieval systems
- *Computer graphics and human-computer interfaces* for spatial applications, visualization, and computer entertainment

Degree in Computer Science

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses: MATH 220, 224, 230; EECS 310
- 4 engineering analysis and computer proficiency courses: GEN ENG 205-1,2,3 or 206-1,2,3; EECS 111
- 4 basic science courses from at least two of the areas below; no more than 2 from earth and planetary sciences/astronomy; no more than 3 in any other area; PHYSICS 135-2,3, 335; BIOL SCI 210-1; and CHEM ENG 275 are recommended but not required
  - *Physics:* PHYSICS 135-2,3, 335
  - *Biological sciences:* BIOL SCI 210-1,2,3; CHEM ENG 275
  - *Chemistry:* CHEM 101, ,102, 103, 171, 172, 210-1,2
  - *Earth and planetary sciences/astronomy:* EARTH 201, 202; ASTRON 220
- 3 design and communications courses: DSGN 106-1,2; ENGLISH 106-1,2; GEN CMN 102
- 5 basic engineering courses
  - *Computer programming:* EECS 211
  - *Probability, statistics, and quality control:* IEMS 201, 303, or EECS 302
  - 3 courses from at least two of the remaining basic engineering areas: computer architecture and numerical methods, electrical science, fluids and solids, materials science and engineering, systems engineering and analysis, and thermodynamics
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 3 required courses: EECS 101, 213, 311
- 5 breadth courses, 1 from each of the following areas (see department website for changes to this list):
  - *Artificial intelligence:* EECS 325, 337, 344, 348, 349, 360
  - *Interfaces:* EECS 330, 332, 351, 352, 370
  - *Software development:* EECS 338, 394
  - *Systems:* EECS 303, 322, 339, 340, 343, 345, 346, 350, 358, 361, 440, 441, 443, 450, 464
  - *Theory:* EECS 328, 335, 336, 356
- 6 depth courses
  - 3 each from two of the following areas (see department website for changes to this list):
    - *Artificial intelligence:* EECS 325, 337, 344, 348, 349, 360
    - *Interfaces:* EECS 330, 332, 351, 352, 370
    - *Security:* EECS 322, 339, 340, 343, 345, 350, 440, 441, 443, 450
    - *Systems:* EECS 322, 339, 340, 343, 345, 350, 358, 361, 440, 441, 442, 443, 450, 464
    - *Theory:* EECS 328, 336, 355, 356, 357, 457, 459; MATH 308
  - Chosen in consultation with advisers.
  - May be a single 6-course depth area with approval.
- 2 project courses: 2 units of 399 or others from the department's list of project courses
- Sections of 395 and 399 may be used for breadth and depth requirements if appropriate; consult program advisers for information.
- Courses at the 400 level are primarily for graduate students but may be open to advanced undergraduate students with the consent of the instructor. EECS 110 may be used as an unrestricted technical elective if taken before EECS 111.

Minor in Computer Science

The department offers a minor in computer science for students who wish to develop stronger competence in computer science while pursuing a degree in another field.

Requirements (15 units)

Prerequisites (6 units)

- MATH 220, 224, 230
- 3 units of engineering analysis: GEN ENG 205-1,2,3 or 206-1,2,3

Minor requirements (9 units)

Core courses (6 units)

- 6 units of computer science: EECS 101, 111, 211, 213, 310, 311; students without prior programming experience may wish to take 110 before 111

Breadth courses (3 units)

- 3 courses from the list of breadth courses (available from the department); each course must be in a different breadth area

Facilities

Students have access to state-of-the-art research and teaching facilities, ranging from laboratories for electronic devices to parallel computers and worldwide distributed testbeds.

Electrical engineering facilities include laboratories for electronic circuits, digital circuits, solid-state electronics, the fabrication of solid-state lasers and other quantum electronic/ photonic devices, thin-film device development, biomedical electronics, microwave techniques, holography and coherent light optics, biological and other control systems, and signal, image, and speech processing.

Computer engineering facilities include laboratories in digital systems design, microprocessor systems, microprogramming, robotics, computer-aided design, and computer networking. The department has major research facilities for work in parallel and distributed computing systems, database systems, computer vision, VLSI design, CAD, robotics, solid-state devices, fiber optics, lasers, computational electromagnetics, electronic materials, and biomedical engineering.

Computer science students benefit from access to computing laboratories that provide Linux, Windows, Solaris, and PocketPC machines, a private network, sensor networks, and the worldwide PlanetLab distributed systems testbed. Students taking courses in experimental computer systems also have access to a special cluster on which they can instantiate their own collections of virtual machines. The department is part of the Microsoft Developer Network Academic Alliance, which provides free or inexpensive access to Microsoft products that are used widely in desktop computing.

Courses

EECS 100-0 Electrons, Photons, and Bits: Adventures in Electrical and Computer Engineering Introduction to contemporary topics in electrical and computer engineering via lectures, demonstrations, lab tours, and invited speakers from industry and government. Weekly reading and writing assignments.

EECS 101-0 An Introduction to Computer Science for Everyone General introduction to historical and current intellectual questions in computer science. Theory, systems, artificial intelligence, interfaces, software development, and interactions with business, politics, law, medicine, engineering, and other sciences.

EECS 110-0 Introduction to Computer Programming Introduction to programming practice using a modern programming language. Analysis and formulation of problems for computer solution. Systematic design, construction, and testing of programs. Substantial programming assignments. Not to be taken for credit with or after EECS 111.

EECS 111-0 Fundamentals of Computer Programming Introduction to principles of programming and procedural thinking. Procedural abstraction, data abstraction, modularity, object-oriented programming. Uses the Scheme programming language and computer facilities. Substantial programming assignments, including numerical and symbolic programs. Required for the computer science degree.

EECS 130-0 Tools and Technology of the World Wide Web Introduction to the theory and practice of developing sites on and technology for the web. Basics of HTML, JavaScript, ASP, and CGI programming.

EECS 195-0 Introductory Topics in Electrical Engineering and Computer Science Topics suggested by students or faculty and approved by the department.

EECS 202-0 Introduction to Electrical Engineering Concepts and applications of electrical engineering. Quantization, binary representation, performance. Power spectral density, digital filtering, fundamental limitations. Control systems, feedback systems. Properties of lasers, amplifiers, passive circuit elements, active circuit elements. Electronic devices and materials.

EECS 203-0 Introduction to Computer Engineering Overview of computer engineering design. Number systems and Boolean algebra. Logic gates. Design of combinational circuits and simplification. Decoders, multiplexers, adders. Sequential logic and flip flops. Introduction to assembly language. Application of concepts to a computer engineering design project.

EECS 205-0 Fundamentals of Computer System Software Basics of assembly language programming. Macros. System stack and procedure calls. Techniques for writing assembly language programs. Features of INTEL 8086/88-based PC. Interfaces between C and assembly codes. Prerequisite: GEN ENG 205-1,2,3,4 or EECS 110; EECS 203 recommended.

EECS 211-0 Object-Oriented Programming in C++ Continuation of 111. Key concepts in software design and systems programming. Object-oriented programming in C++, design of interpreters and compilers, and register machines. Required for the computer science degree. Prerequisite: 110 or 111 or knowledge of any programming language. Not to be taken for credit with or after 230 or 231.

EECS 213-0 Introduction to Computer Systems The hierarchy of abstractions and implementations that make up a modern computer system; demystifying the machine and the tools used to program it; systems programming in C in the UNIX environment. Preparation for upper-level systems courses. Prerequisite: 211 or 230.

EECS 221-0 Fundamentals of Circuits Circuit analysis and network theorems; linearity and superposition; series/parallel combinations of R, L, and C circuits; sinusoidal forcing; complex frequency and Bode plots; mutual inductance and transformers; two-port networks; Fourier analysis; response of circuits to periodic nonsinusoidal sources. Prerequisite: 202.

EECS 222-0 Fundamentals of Signals and Systems Comprehensive introduction to analysis of continuous and discrete-time signals and systems. Linear time-invariant systems, convolution. Fourier series representations of periodic signals. Continuous time and discrete time Fourier transforms. Laplace transform; z-transform. Prerequisite: 202.

EECS 223-0 Fundamentals of Solid-State Engineering Crystalline state of matter; quantum phenomena and quantum mechanics; electrons in atoms, atoms in crystals, electrons in crystals; semiconductors; thermal properties of crystals, electrical properties of crystals and semiconductors; p-n junction. Prerequisites: 202; PHYSICS 135-3; MATH 234.

EECS 224-0 Fundamentals of Electromagnetics and Photonics Concepts of flux, potential, gradient, divergence, curl, and field intensity. Boundary conditions and solutions to Laplace and Poisson equations. Capacitance and inductance calculations. Conductors, insulators, and magnetic materials. Prerequisites: 202, 221; PHYSICS 135-2; MATH 234; or consent of instructor.

EECS 225-0 Fundamentals of Electronics Diode, BJT, and FET circuits; design using ideal operational amplifiers; feedback; frequency response; biasing; current sources and mirrors; small-signal analysis; design of operational amplifiers. Prerequisites: 221, 223.

EECS 230-0 Programming for Computer Engineers Introduction to computer programming in an object-oriented language. Emphasis on applications to computer systems, computer simulation, and discrete optimization. Basic principles of software engineering. Not to be taken for credit with or after 211 or 231. Prerequisites: GEN ENG 205-1,2.

EECS 231-0 Advanced Programming for Computer Engineers Object-oriented programming, classes and data hiding, dynamic object construction and destruction, derived classes and inheritance, virtual functions; file processing; introduction to UNIX; testing and test generation. Not to be taken for credit with or after 211 or 230. Prerequisite: 110 or knowledge of a programming language.

EECS 250-0 Physical Electronics and Devices The physical basis of electronic and optoelectronic devices and their application in analog and digital systems. Diodes, transistors, LEDs, photodetectors, and lasers are described, and their properties are explored. Prerequisites: 221; PHYSICS 135-2.

EECS 270-0 Applications of Electronic Devices DC and AC networks, rectifiers, transistor amplifiers, feedback and operational amplifiers, digital electronics, and microprocessors. Not open to electrical engineering degree candidates. Prerequisites: MATH 224; PHYSICS 135-2; or equivalent.

EECS 295-0 Intermediate Topics in Electrical Engineering and Computer Science Topics suggested by students or faculty and approved by the department.

EECS 302-0 Probabilistic Systems and Random Signals Basic concepts of probability theory and statistics, random variables, moments; multiple random variables, conditional distributions, correlation; random signals; applications to engineering systems. Prerequisite: MATH 234.

EECS 303-0 Advanced Digital Logic Design Overview of digital logic design. Technology review. Delays, timing in combinational and sequential circuits, CAD tools, arithmetic units such as ALUs and multipliers. Introduction to VHDL. Prerequisite: 203.

EECS 307-0 Communications Systems Analysis of analog and digital communications systems, including modulation, transmission, and demodulation of AM, FM, and TV systems. Design issues, channel distortion and loss, bandwidth limitations, additive noise. Prerequisites: 222, 302.

EECS 308-0 Advanced Electromagnetics and Photonics Electromagnetic waves, transmission lines; impedance transformation; transients on lines; electrostatics, conductors, and capacitors; magnetostatics and inductors; wave reflection and transmission; electromagnetic motor, Maxwell's equations; metallic waveguides and wave transmission; antenna and diffraction, antenna arrays, communication, and radar. Prerequisite: 224.

EECS 310-0 Mathematical Foundations of Computer Science Basic concepts of finite and structural mathematics. Sets, axiomatic systems, the propositional and predicate calculi, and graph theory. Application to computer science: sequential machines, formal grammars, and software design. Prerequisites: 110 or 111; MATH 230.

EECS 311-0 Data Structures and Data Management The design, implementation, and analysis of abstract data types; data structures and their algorithms. Topics include data and procedural abstraction, linked lists, stacks, queues, binary trees, searching, and sorting. Required for the computer science degree. Prerequisite: 211 or 230.

EECS 313-0 Telecommunication Networks for Multimedia Signals and bandwidth concepts, spectra, basics of electronics, information and coding, modulation, multiplexing, transmission systems, transmission media, analog versus digital communications, computer networks, and switching techniques. Not for electrical engineering or computer engineering degree candidates.

EECS 317-0 Data Management and Information Processing Data representation, file and record organization, linear and linked lists, and scatter storage techniques. Sorting and searching algorithms. Solving problems involving large databases. Not for students in computer science. Prerequisite: 110, 111, or programming experience.

EECS 321-0 Programming Languages Introduction to key parts of programming languages: syntax, semantics, and pragmatics. Students implement a series of interpreters that show how various aspects of programming languages behave. Prerequisites: 111, 311.

EECS 322-0 Compiler Construction Overview of compilers and context-free languages, top-down parsing, LL(1) parser construction, translation grammars, implementation of lexical analyzer, parser and translator, compiler optimization, error handling, and recovery. Prerequisite: 311.

EECS 325-1,2 Artificial Intelligence Programming Introduction to LISP and programming knowledge-based systems and interfaces. Strong emphasis on writing maintainable, extensible systems. Topics include semantic networks, frames, pattern matching, deductive inference rules, case-based reasoning, and discrimination trees. Project driven. Substantial programming assignments. Prerequisite: 110, 111, or programming experience.

EECS 328-0 Numerical Methods for Engineers Introduction to numerical methods; numerical differentiation, numerical integration, solution of ordinary and partial differential equations. Students write programs in FORTRAN, C, or Pascal using methods presented in class. Prerequisites: GEN ENG 205-1,2,3; MATH 220, 224, 230.

EECS 330-0 Human-Computer Interaction Introduction to human-computer interaction and the design of systems that work for people and their organizations. Understanding the manner in which humans interact with and use their computers for productive work. Prerequisite: programming experience.

EECS 332-0 Digital Image Analysis Introduction to computer and biological vision systems, image formation, edge detection, image segmentation, texture, representation and analysis of two-dimensional geometric structures, and representation and analysis of three-dimensional structures. Prerequisites: 311; IEMS 202; MATH 240.

EECS 333-0 Introduction to Communication Networks Data communication basics. Telephone, cellular, cable, and computer networks. Layered network architectures, models, and protocols. Switching, routing, flow control, and congestion control. Medium access control, ARQ, and local area networks. Queuing models and network performance analysis. Prerequisite: 302; IEMS 202; MATH 320-1,2,3; or equivalent basic probability theory.

EECS 334-0 Introduction to Computer Vision Introduction to computer and biological vision systems, image formation, edge detection, image segmentation, texture, and representation and analysis of two- and three-dimensional structures. Prerequisites: 311; IEMS 201.

EECS 335-0 Introduction to the Theory of Computation Mathematical foundations of computation, including computability, relationships of time and space, and the P vs. NP problem. Prerequisite: 310 or consent of instructor.

EECS 336-0 Design and Analysis of Algorithms Analysis techniques: solving recurrence equations. Algorithm design techniques: divide and conquer, the greedy method, backtracking, branch-and-bound, and dynamic programming. Sorting and selection algorithms, order statistics, heaps, and priority queues. Prerequisite: 310, 311, or consent of instructor.

EECS 337-0 Natural Language Processing Semantics-oriented introduction to natural language processing, broadly construed. Representation of meaning and knowledge inference in story understanding, script/frame theory, plans and plan recognition, counterplanning, and thematic structures. Prerequisite: 348 or consent of instructor.

EECS 338-0 Practicum in Intelligent Information Systems A practical excursion into building intelligent information systems. Students develop a working program in information access, management, capture, or retrieval. Project definition, data collection, technology selection, implementation, and project management.

EECS 339-0 Introduction to Database Systems Data models and database design. Modeling the real world: structures, constraints, and operations. The entity relationship to data modeling (including network hierarchical and object-oriented), emphasis on the relational model. Use of existing database systems for the implementation of information systems. Prerequisite: 311.

EECS 340-0 Introduction to Networking A top-down exploration of networking using the five-layer model and the TCP/IP stack, covering each layer in depth. Students build web clients, servers, and a TCP implementation and implement routing algorithms. Prerequisite: 311.

EECS 343-1,2 Operating Systems Fundamental overview of operating systems. **1.** Operating system structures, processes, process synchronization, deadlocks, CPU scheduling, and memory management. **2.** File systems, secondary storage management, issues in distributed systems, case studies, and special topics. Requires substantial programming projects. Prerequisites: 311 and either 213 or 205 and 231.

EECS 344-0 Design of Computer Problem Solvers Principles and practice of organizing and building artificial intelligence reasoning systems. Pattern-directed rule systems, truth-maintenance systems, and constraint languages. Prerequisite: 348 and 325-1 or equivalent LISP experience.

EECS 345-0 Distributed Systems Basic principles behind distributed systems (collections of independent components that appear to users as a single coherent system) and main paradigms used to organize them. Prerequisites: 340, 343.

EECS 346-0 Microprocessor System Design Structure and timing of typical microprocessors. Sample microprocessor families. Memories, UARTS, timer/counters, serial devices, and related devices. MUX and related control structures for building systems. Sample single-board computers. Standard bus structures. Interrupt programming. Hardware/software design tradeoffs. Prerequisites: 203, 205.

EECS 347-1 Microprocessor System Projects I Programmable logic devices such as PAL and FPGA. Design, prototype, and test individual projects involving microprocessors and programmable logic devices. Prerequisites: 346.

EECS 347-2 Microprocessor System Projects II Students design, prototype, and test individual projects involving microprocessors and related devices, such as PAL/FPGA and special-purpose ICs. Embedded-system tools such as special-purpose compilers and ICE (in-circuit emulation). Manufacturing issues such as PCB layout. Survey of microprocessor platforms. Prerequisite: 347-1.

EECS 348-0 Introduction to Artificial Intelligence Core techniques and applications of AI. Representing, retrieving, and applying knowledge for problem solving. Hypothesis exploration. Theorem proving. Vision and neural networks. Prerequisite: 325-1 or LISP programming experience.

EECS 349-0 Machine Learning Machine learning is the study of algorithms that improve through experience. Topics covered typically include Bayesian learning, decision trees, genetic algorithms, neural networks, Markov models, and reinforcement learning. Assignments include programming projects and written work. Prerequisite: 348.

EECS 350-0 Introduction to Computer Security Basic principles and practices of computer and information security. Software, operating system, and network security techniques, with detailed analysis of real-world examples. Topics include cryptography, authentication, software and operating system security (e.g., buffer overflow), Internet vulnerability (DoS attacks, viruses/worms, etc.), intrusion detection systems, firewalls, VPN, and web and wireless security. Prerequisite: 213 or equivalent or consent of instructor; 340 highly recommended.

EECS 351-0 Introduction to Computer Graphics Mathematical software and hardware requirements for computer graphics systems. Data structures and programming languages. Random displays. Graphic applications. Prerequisite: 311.

EECS 352-0 Machine Perception of Music and Audio Machine extraction of musical structure in audio and MIDI and score files, covering areas such as source separation and perceptual mapping of audio to machine-quantifiable measures. Prerequisite: GEN ENG 205-2, EECS 211, EECS 231, or prior programming experience in MATLAB.

EECS 353-0 Digital Microelectronics Logic families, comparators, A/D and D/A converters, combinational systems, sequential systems, solid-state memory, large-scale integrated circuits, and design of electronic systems. Prerequisites: 203, 225.

EECS 354-0 Network Penetration and Security Practical tools for vulnerability assessment and defense of computer and communication systems. Prerequisite: 213 or 205 and 231.

EECS 355-0 Introduction to FPGA Design Overview of computer-aided design tool flow for ASIC and FPGA design. Synthesis from hardware description languages and creation of finite-state machines. Differences between FPGA and ASIC design flows. Exploration of concepts in several projects. Prerequisite: 303.

EECS 356-0 Introduction to Formal Specification and Verification Introduction to formal techniques used for system specifications and verifications: temporal logic, set theory, proofs, and model checking. TLA+ (Temporal Logic of Actions) specifications. Safety and liveness properties. Real-time specs and verifications.

EECS 357-0 Introduction to VLSI CAD VLSI physical design, including logic design, architectural design, and packaging. Development of CAD tools for VLSI physical design. Prerequisites: 303; EECS 311.

EECS 358-0 Introduction to Parallel Computing Introduction to parallel computing for scientists and engineers. Shared-memory parallel architectures and programming, distributed memory, message-passing data-parallel architectures, and programming. Prerequisites: 361; 211 or 230.

EECS 359-0 Digital Signal Processing Discrete-time signals and systems. Discrete-time Fourier transform, z-transform, discrete Fourier transform, digital filters. Prerequisite: 222.

EECS 360-0 Introduction to Feedback Systems Linear feedback control systems, their physical behavior, dynamical analysis, and stability. Laplace transform, frequency spectrum, and root locus methods. System design and compensation using PID and lead-lag controllers. Digital implementations of analog controllers. Not to be taken for credit with or after MECH ENG 391. Prerequisite: 222.

EECS 361-0 Computer Architecture Design and understanding of the computer system as a whole unit. Performance evaluation and its role in computer system design; instruction set architecture design, datapath design and optimizations (e.g., ALU); control design; single cycle, multiple cycle, and pipeline implementations of processor. Hazard detection and forwarding; memory hierarchy design; cache memories, virtual memory, peripheral devices, and I/O. Prerequisites: 205, 303.

EECS 362-0 Computer Architecture Project Quarter-long team project designing a processor for a complete instruction set. Involves ISA design, design of components, datapath, and control for a pipelined processor to implement the ISA. Students use industrial-strength design tools and VHDL as the design specification language. Designs are evaluated using benchmark programs for correctness and performance. Prerequisite: 361.

EECS 363-0 Digital Filtering Recursive and nonrecursive digital filters, decimation and interpolation, A/D and D/A conversion as digital filtering problems. Implementation of nonrecursive filters via FFT, quantization problems, e.g., companding and limit cycles. Prerequisite: 359.

EECS 366-0 Designing and Constructing Models with Multiagent Languages How to translate a situation into a multiagent model, construct multiagent models and networked situations, and analyze their behavior and performance. Prerequisite: 311.

EECS 369-0 Introduction to Sensor Networks Basic hardware and software platforms for sensor networks. Various algorithmic techniques for data routing, query processing, and tracking. Prerequisite: 343 or 340.

EECS 370-0 Computer Game Design Plot, narrative, and character simulation for creating game worlds; artificial intelligence for synthetic characters; tuning gameplay. Substantial programming and project work. Prerequisites: 311; 1 unit of 322, 343, 348, or 351.

EECS 371-0 Knowledge Representation and Reasoning Principles and practices of knowledge representation, including logics, ontologies, common-sense knowledge, and semantic web technologies. Prerequisite: 348, 325, or equivalent experience with artificial intelligence.

EECS 372-0 Designing and Constructing Models with Multiagent Languages Exploration and analysis of multiagent models, which simulate "emergent" scientific phenomena in a wide variety of content domains.

EECS 374-0 Introduction to Digital Control Discrete dynamics systems; discrete models of continuous systems feedback and digital controllers; analog-digital conversion; digital control design including PID, lead/lag, deadbeat, and model-matching controllers. Prerequisite: 360.

EECS 378-0 Digital Communications Sampling and time-division multiplexing, baseband digital signals and systems. Coded pulse modulation, error control coding, digital modulation systems, information measure and source encoding, and introduction to spread spectrum communications. Prerequisites: 302, 307.

EECS 379-0 Lasers and Coherent Optics Optical resonators; fundamental operation of lasers; mode-locking and Q-switching; optical propagation and diffraction; Gaussian beams; thin-lens imaging; optical signal processing. Prerequisites: 222, 224.

EECS 380-0 Wireless Communications Overview of existing and emerging wireless communications systems; interference, blocking, and spectral efficiency; radio propagation and fading models; performance of digital modulation in the presence of fading; diversity techniques; code-division multiple access. Prerequisite: 378.

EECS 381-0 Electronic Properties of Materials Fundamental properties of electrons in materials. Classical and quantum mechanical descriptions of free and bound electrons. Optical, electrical, thermal, and magnetic properties of materials. Microelectronic, optoelectronic, magnetic recording, superconductivity. Prerequisites: 223 and 224 or consent of instructor.

EECS 382-0 Photonic Information Processing Introduction to photonic information processing; coherent and incoherent light; electro-optic and acousto-optic modulation; optical signal processing; holography; optical storage. Prerequisites: 222 and 224 or consent of instructor.

EECS 383-0 Fiber-Optic Communications Semiconductor diode lasers, internal modulation, electro-optic modulation, coherent and incoherent detection, optical fibers and their properties, optical amplifiers, communication systems, optical networks. Prerequisites: 223, 224.

EECS 384-0 Solid-State Electronic Devices Energy-band model for semiconductors; carrier statistics and transport; diodes, bipolar and field-effect transistors; integrated circuits, optoelectronic and heterojunction devices. Prerequisite: 381 or consent of instructor.

EECS 385-0 Optoelectronics Introduction to solid-state optoelectronic devices; display devices, laser diodes, photodetectors, and light modulators; optical waveguides and fibers; system application of optoelectronic devices. Prerequisite: 381 or consent of instructor.

EECS 386-0 Computational Electromagnetics and Photonics Introduction to the finite-difference time-domain (FDTD) method in numerical modeling of electromagnetic and optical wave interactions with engineering structures. Finite differences; Maxwell's equations; numerical dispersion and stability; free-space and waveguide field sources; absorbing boundary conditions; material dispersions and nonlinearities; modeling examples in modern electromagnetic and optical engineering. Prerequisite: 308.

EECS 388-0 Nanotechnology Physics and fabrication of photonic and electronic devices. Physics of semiconductors: crystal structures, reciprocal lattice, elements of quantum mechanics, heterojunctions, quantum wells, and superlattices. Bulk crystal, thin-film, and epitaxial growth technologies. Device processing technologies: diffusion oxidation, ion implantation, annealing, etching, and photolithography. Prerequisite: 223 or consent of instructor.

EECS 389-0 Superconductivity and Its Applications Properties of materials in the superconducting state; charge flow dynamics of type II superconductors; high-Tc superconductors; applications for computers and high-frequency devices. Prerequisite: 381 or consent of instructor.

EECS 390-0 Introduction to Robotics Homogeneous vectors and planes; homogeneous transformation, position and orientation transformations, kinematics and inverse kinematic solutions of robot manipulators; Jacobian and inverse Jacobian relation; robot trajectory and task planning; dynamic formulation and computation of robot manipulators; robot programming and control systems. Prerequisite: 230.

EECS 391-0 VLSI Systems Design Design of CMOS digital integrated circuits, concentrating on architectural and topological issues. Tradeoffs in custom design, standard cells, gate arrays. Use of VLSI design tools on a small project. Prerequisite: 303.

EECS 392-0 VLSI Systems Design Projects Design of a cutting-edge VLSI chip. Teams of 5 to 10 students undertake a large circuit design problem, going from specification to VLSI implementation while optimizing for speed, area, and/or power. Group collaboration and engineering design. Prerequisite: 391.

EECS 393-0 VLSI Design and Analysis of High-Speed Integrated Circuits Issues that arise in the design and analysis of VLSI circuits at high speeds, such as buffer sizing, repeater insertion, noise, electromigration, Elmore decay, scaling trends, and power consumption. Prerequisite: 391.

EECS 394-0 Software Project Management and Development Software development methodologies. Object-oriented analysis and design, CASE tools, software life cycle. Project management tools, programming teams. Executable specifications, automatic test generation. Prerequisite: 343 or equivalent programming experience.

EECS 395-0 Special Topics in Electrical Engineering and Computer Science Topics suggested by students or faculty and approved by the department.

EECS 398-0 Electrical Engineering Design Design of electrical and electronic devices, circuits, and systems by the application of the engineering sciences, economics, and Institute of Electrical and Electronics Engineers or other national standards. Prerequisite: senior standing.

EECS 399-0 Projects Seminar and projects for advanced undergraduates on subjects of current interest in electrical and computer engineering.

ENGINEERING DESIGN

See Manufacturing and Design Engineering for the certificate in engineering design.

ENGINEERING SCIENCES AND APPLIED MATHEMATICS

www.esam.northwestern.edu

The Department of Engineering Sciences and Applied Mathematics offers course work in applied mathematics and administers an undergraduate program leading to a BS in applied mathematics and a graduate program in applied mathematics.

The applied mathematics program is intended to provide the knowledge necessary for applying mathematical ideas and techniques to the problems that arise in engineering or science. It is expected that a student receiving a BS in applied mathematics would have the background for suitable employment in industry or for graduate study in either mathematics (pure or applied) or an engineering field, including computer science and operations research. To achieve these goals, the applied mathematics program is designed to be flexible and allow the student to concentrate a substantial part of the course work either in mathematics or one or more areas of application.

Degree in Applied Mathematics

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses
  - PHYSICS 135-2,3
  - 2 courses from the following list:
    - *Biological sciences:* BIOL SCI 210-1,2,3; CHEM ENG 275
    - *Chemistry:* CHEM 101, 102, 103, 171, 172, 210-1,2
    - *Earth and planetary sciences/astronomy:* EARTH 201, 202; ASTRON 220
- 3 design and communications courses
- 5 basic engineering courses
  - EECS 230 or 231
  - 4 courses from at least three of the following areas:
    - *Computer architecture and numerical methods:* EECS 203, 205, 328
    - *Electrical science:* EECS 202, 221, 222, 223, 224, 270; MECH ENG 233
    - *Fluids and solids:* BMD ENG 270, 271; CHEM ENG 321; CIV ENV 216, 219; MECH ENG 241
    - *Materials science and engineering:* MAT SCI 201, 203, *or* 301
    - *Systems engineering and analysis:* CHEM ENG 210; CIV ENV 304; IEMS 310, 313, 326
    - *Thermodynamics:* BMD ENG 250; CHEM 342-1; CHEM ENG 211; MAT SCI 314, 315; MECH ENG 220, 370 (MECH ENG 220 may not be taken with CHEM 342-1 or CHEM ENG 211)
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 5 engineering sciences and applied mathematics courses: ES APPM 311-1,2, 322, 346, 421-1
- ES APPM 311-3 or MATH 325
- MATH 334
- 2 courses chosen from EECS 302; IEMS 202, 303; IEMS 310 or 313; MATH 330-1,2,3
- 1 course chosen from ES APPM 339, 421-2, 3, 495 (subject to department approval)
- 4 courses in engineering or the sciences at the 300-level or higher leading to an approved concentration in one of the following areas:
  - *Engineering*
  - *Mathematical social sciences (e.g., economics)*
  - *Mathematics (e.g., discrete mathematics or analysis)*
  - *Numerics*
  - *The sciences*
- 2 technical electives at the 300 level or higher in engineering, science, or mathematics

Courses

ES APPM 252-1,2 Honors Calculus for Engineers Alternative to standard calculus sequence. Covers more material at a deeper level with more applications. Satisfies same requirements as MATH 230 and 234. Prerequisite: invitation or consent of instructor.

ES APPM 311-1,2 Methods of Applied Mathematics Ordinary differential equations; Sturm-Liouville theory, properties of special functions, solution methods including Laplace transforms. Fourier series: eigenvalue problems and expansions in orthogonal functions. Partial differential equations: classification, separation of variables, solution by series and transform methods. Prerequisite: GEN ENG 205-4, 206-4, or MATH 250.

ES APPM 311-3 Methods of Applied Mathematics: Complex Variables Imaginary numbers and complex variables, analytic functions, calculus of complex functions, contour integration with application to transform inversion, conformal mapping. May be taken independently of 311-1,2. Prerequisite: GEN ENG 205-4, 206-4, or MATH 250.

ES APPM 321-0 Modeling Soft Matter: Networks, Membranes, Fluctuations Fundamental mathematical tools (e.g., differential geometry, variational calculus) are applied to modern concepts of soft-matter structure and mechanics in various fields (e.g., biological membranes, polymers). Prerequisites: 311-1,2 or consent of instructor.

ES APPM 322-0 Applied Dynamical Systems Example-oriented survey of nonlinear dynamical systems, including chaos. Combines numerical exploration of differential equations describing physical problems with analytic methods and geometric concepts. Applications to mechanical, fluid dynamical, electrical, chemical, and biological systems. Prerequisites: 311-1,2 or equivalent or consent of instructor.

ES APPM 346-0 Modeling and Computation in Science and Engineering Advanced techniques for initial value problems, differential algebraic systems, bifurcations, chaos, and partial differential equations. Applications drawn from different physical areas. Prerequisites: MATH 234, 240; MATH 250 or GEN ENG 205-4; PHYSICS 135-1,2 or equivalent; familiarity with a programming language; or consent of instructor.

ES APPM 399-0 Projects Special studies to be carried out under faculty direction. Credit to be arranged.

See the Cross-School Options chapter for opportunities open to all Northwestern undergraduates.

ENVIRONMENTAL ENGINEERING

See Civil and Environmental Engineering.

INDUSTRIAL ENGINEERING AND MANAGEMENT SCIENCES

www.iems.northwestern.edu

Northwestern's industrial engineering students graduate with the skills needed to create, design, analyze, and improve the operation of complex organizational systems, e.g., financial systems, information systems, production systems, logistics, and transportation. All students acquire an understanding of statistics, economics, optimization, computing, and simulation techniques. Elective opportunities include courses in business management, advanced economics and mathematics, quality control and reliability, communications and information systems, and production and supply-chain management. Realistic (i.e., open-ended and ill-defined) problems are used to help students refine the application of these principles as well as their ability to work in teams and to communicate their results effectively. These are the experiences that employers find most valuable in our graduates regardless of the field they enter.

Students may pursue an optional concentration using technical electives and other courses from one or more of the following areas: economics and finance, general business management, industrial behavioral sciences, mathematical sciences/graduate research, production and logistics, and statistics and quality control.

Many industrial engineering graduates eventually assume management positions. In preparation for such careers, students take full advantage of the additional academic, business, and leadership programs available at Northwestern: a major or minor in economics, the business enterprise certificate for engineers, the Undergraduate Leadership Program, the Business Institutions Program, study abroad, and the co-op program. The two-quarter senior design project allows students to integrate all of these experiences.

Degree in Industrial Engineering

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses
  - 4 courses from at least two of the following areas:
    - *Physics:* PHYSICS 135-2,3, 335
    - *Biological sciences:* BIOL SCI 210-1,2,3; CHEM ENG 275
    - *Chemistry:* CHEM 101, 102, 103, 171, 172, 210-1,2
    - *Earth and planetary sciences/astronomy:* EARTH 201, 202; ASTRON 220
  - No more than 2 courses from earth and planetary sciences/astronomy
  - No more than 3 courses in any other area
  - PHYSICS 135-2 and 1 unit of chemistry recommended

- 3 design and communications courses
- 5 basic engineering courses:
  - EECS 230
  - EECS 317 or 328
  - IEMS 326
  - 2 courses from BMD ENG 220, 250, 270, 271; CHEM 342-1; CHEM ENG 210, 211, 312, 321; CIV ENV 216, 219, 304, 306; EECS 202, 203, 205, 211, 221, 222, 223, 224, 231, 270, 302; ES APPM 346; MAT SCI 201, 203, 301, 314, 315; MECH ENG 220, 233, 241, 359, 370 (MECH ENG 220 may not be taken with CHEM 342-1 or CHEM ENG 211)
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 2 probability and statistics courses: IEMS 202, 303
- 3 operations research courses: IEMS 313, 315, 317
- 1 applied behavioral science course: IEMS 340 or 342
- 1 production and logistics course chosen from IEMS 381, 382, 383, 385
- 2 senior design project courses
  - IEMS 390, 391, or 392
  - IEMS 393
- 7 electives
  - 3 industrial engineering/operations courses from IEMS 304, 305, 306, 307, 373, 381, 382, 383, 385, 391
  - 1 management science course from IEMS 325, 340, 341, 342, 390, 392
  - 3 engineering courses at the 200 level or higher or any course from the general technical elective group (available from the department); no more than 2 units of 399 are allowed; no more than 2 courses in this group may be taken P/N; no other electives may be taken P/N
- Concentration (optional)
  Students choose at least 4 courses from an approved list. Students may pursue more than one concentration. Concentrations may be created from courses that satisfy other requirements or concentrations. A list of available concentration areas may be found on the department website.

Courses

IEMS 201-0 Introduction to Statistics Collecting data; summarizing and displaying data; drawing conclusions from data; probability background, confidence intervals, hypotheses tests, regression, correlation. Not open to industrial engineering degree candidates. Not to be taken for credit with or after STAT 210.

IEMS 202-0 Probability Introduction to probability theory and its applications. Random variables and distributions including binomial, Poisson, exponential, and normal. Monte Carlo simulation. Examples in reliability, inventory, finance, and statistics. Homework, labs, and exams. Not to be taken for credit with or after MATH 310-1. Prerequisite: concurrent enrollment in MATH 234.

IEMS 210-0 Methods, Standards, and Work Design Introduction to traditional topics in industrial engineering, including time study, work measurement, standards, and design. This course enables industrial engineering students to understand and assume traditional industrial engineering roles upon graduation. Prerequisite: sophomore standing and knowledge of probability and statistics.

IEMS 225-0 Principles of Entrepreneurship Introduction to essential elements of building one's own business, from brainstorming ideas and assessing opportunities to pitching a business idea. History of entrepreneurship and the entrepreneurial psyche. Business plan fundamentals, including strategy, finance, accounting, marketing, operations, and choosing the ideal management team. May not be taken after 325.

IEMS 295-0 Introductory Topics in Industrial Engineering Topics suggested by students or faculty members and approved by the department; taught at an intermediate level.

IEMS 303-0 Statistics Statistical methods for data analysis. Descriptive plots and statistics; observational studies and experiments; confidence interval estimation; hypothesis testing; regression and correlation. Homework, labs, and project. Not to be taken for credit with or after STAT 320-1. Prerequisite: 202 or equivalent.

IEMS 304-0 Statistical Methods for Data Mining Advanced statistical methods. Multiple regression; analysis of variance; design and analysis of single-factor and multifactor experiments; categorical data; nonparametric methods. Homework and project. Not to be taken for credit with or after STAT 320-2. Prerequisite: 303 or equivalent.

IEMS 305-0 Statistical Methods for Quality Improvement Methods for controlling and improving industrial processes. Control charts; process capability; gage repeatability and reproducibility. Multifactor experiments; screening experiments; robust design. Homework, labs, and project. Prerequisite: 303 or equivalent.

IEMS 306-0 Decision Analysis Theory and practice of analyzing decisions in the public and private sectors. Multiple objectives; influence diagrams; decision trees; sensitivity analysis; probability assessment; utility; human biases. Problems, cases, and projects. Prerequisite: 202 or equivalent.

IEMS 307-0 Quality Improvement by Experimental Design Methods for designing and analyzing industrial experiments. Blocking; randomization; multiple regression; factorial and fractional factorial experiments; response surface methodology; Taguchi's robust design; split plot experimentation. Homework, labs, and project. Prerequisite: 303 or equivalent.

IEMS 310-0 Operations Research Survey of operations research techniques. Linear programming, decision theory, stochastic processes, game theory. Not open to industrial engineering degree candidates. May not be taken with 313 or 315.

IEMS 313-0 Deterministic Models and Optimization Formulation and solution of applicable optimization models, including linear, integer, nonlinear, and network problems. Efficient algorithmic methods and use of computer modeling languages and systems. Homework, exams, and project. Prerequisites: GEN ENG 205-1; MATH 230; sophomore standing.

IEMS 315-0 Stochastic Models and Simulation Modeling and analysis of dynamic systems subject to uncertainty. Integrated approach to stochastic analysis and simulation. Rough-cut analysis of queuing systems. Homework, exams, computer labs, and project. Prerequisites: 202, 303; GEN ENG 205-1.

IEMS 317-0 Discrete-Event Systems Simulation Computer simulation of discrete-change systems subject to uncertainty. Choice of input distributions; development of models; design and analysis of simulation experiments. Miniprojects, exams, and computer labs. Prerequisites: 303; 310 or 315.

IEMS 325-0 Engineering Entrepreneurship Overview of the entrepreneurial process from an engineering perspective. Idea generation, planning, financing, marketing, protecting, staffing, leading, growing, and harvesting. Students write startup business plans. Lectures, guest speakers, and case studies. Prerequisite: 1 course in accounting or finance such as 326 or ECON 260.

IEMS 326-0 Economics and Finance for Engineers Principles of corporate finance; financial decisions of firms; value; risk and return; investment and capital budgeting decisions under certainty and uncertainty; performance evaluation. Homework and exams. Prerequisites: MATH 220; basic understanding of probability and economics recommended; students will not receive credit for 326 after taking KELLG FE 310.

IEMS 340-0 Field Project Methods Use of field research methods to solve management problems. Assignments focus on individual student projects. Students define projects, design field studies and pilot tests of data collection instruments, and present results. Prerequisite for students who are not degree candidates: consent of instructor.

IEMS 341-0 Social Network Analysis The use of social network analysis to understand the growing connectivity and complexity in the world around us on different scales, ranging from small groups to the World Wide Web. How we create social, economic, and technological networks, and how they enable and constrain attitudes and behaviors.

IEMS 342-0 Organizational Behavior Manager's view of tools available to recruit, develop, appraise, compensate, organize, and lead a team going through change. Application of psychological principles relating to human dynamics, motivation, teams, power, and organizational culture. Lectures, guest speakers, and exams. Work experience recommended.

IEMS 343-0 Project Management for Engineers A case study–based exploration of the body of project management knowledge. Key topics include project scheduling, risk management, project leadership, small-group dynamics, project methodologies, lifecycle concepts, and project controls. A Socratic approach is taken to exploring various case studies in the context of established and leading-edge project-management concepts. Prerequisites: 303 and 342 recommended.

IEMS 345-0 Negotiations and Conflict Resolution for Engineers Highly interactive case-study-based exploration of the field of negotiation and dispute resolution. Students interact in simulated negotiations and disputes ranging in complexity from single-party/single-issue to multiparty/multi-issue cases that illustrate integrative negotiation techniques. Also, dispute resolution techniques in the context of typical industrial situations. Prerequisites: 303 and 342 recommended.

IEMS 373-0 Introduction to Financial Engineering Financial markets, derivative securities, risk management, mathematical models in finance. Foreign exchange, debt, equity, commodity markets. Investing, trading, hedging, arbitrage. Forwards, futures, options, swaps, exotic derivatives. Models of price dynamics, binomial model, introduction to Black-Scholes theory and Monte Carlo simulation. Homework, projects, and guest speakers. Prerequisites: 315, 326, Math 234, EECS 230, or equivalent or consent of instructor.

IEMS 381-0 Supply-Chain Modeling and Analysis Application and development of mathematical modeling tools for the analysis of strategic, tactical, and operational supply-chain problems including facility location, customer assignment, vehicle routing, and inventory management. Related topics including the role of information and decision support systems in supply chains. Homework, exams, and project. Prerequisite: 313.

IEMS 382-0 Production Planning and Scheduling Applications of operations research methods to practical problems of production planning and inventory control. Forecasting; aggregate planning; deterministic and stochastic inventory models; MRP; JIT; variability; scheduling in production and service systems. Case studies, homework, and exams. Prerequisites: 202; 310 or 313.

IEMS 383-0 Service Operations Management Exploration of service industries: cost-reduction and service-enhancement models, location planning, workforce scheduling, yield management, queuing analysis, and call-center management. Prerequisites: 313, 315.

IEMS 385-0 Introduction to Health Systems Management Health systems, lean concepts, patient-flow analysis, inference, and data-driven knowledge generation, decisions, and change. Forecasting, operations, and optimization of health resources. Prerequisites: 303, 313.

IEMS 390-0 Systems Management Introduction to systems problems and methods. Small-group development of potential classwide projects to be carried out the following quarter. Identifying projects, team skills, presenting plans and proposals. Prerequisite: 340.

IEMS 391-0 Industrial Engineering Design Case studies and small-scale projects involving application of operations research techniques to complex-decisions problems. Mathematical modeling, optimization, and policy analysis in public and private sector systems. Written and oral presentations of analyses. Prerequisite: senior standing; 313 and 315 for industrial engineering degree candidates; 310 for manufacturing engineering degree candidates.

IEMS 392-0 Systems Project Management Project management methods applied to analysis and design of a complex real-world system. Students choose and carry out a single classwide project. Planning, organizing, staffing, directing, and controlling; working with clients and stakeholders. Prerequisite: senior standing.

IEMS 393-0 Industrial Engineering Design Project Large-scale, open-ended team projects from selected fields of industrial engineering. Systems approach requiring establishment of objectives and criteria, analysis and synthesis of alternatives, feasibility, trade-offs, testing, and evaluation. Written and oral reports. Prerequisite: 390, 391, or 392.

IEMS 395-0 Special Topics in Industrial Engineering Topics suggested by students or faculty members and approved by the department.

IEMS 399-0 Independent Study Independent study on an industrial engineering topic supervised by a faculty member.

MANUFACTURING AND DESIGN ENGINEERING

www.segal.northwestern.edu

The Segal Design Institute is the unit of the McCormick School that promotes the importance of design throughout the undergraduate curriculum and is dedicated to fostering innovation among engineering students and faculty.

Through the institute students gain design experience using state-of-the-art tools by participating in projects on topics that range from blast-resistant structures to HIV monitoring in the developing world. They also develop portfolios to showcase their design work.

Degree in Manufacturing and Design Engineering

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses: PHYSICS 135-2,3; 2 courses from CHEM 101, 102, 103, 171, 172, 210-1,2
- 3 design and communications courses
- 5 basic engineering courses
  - *Electrical science:* MECH ENG 233
  - *Fluids and solids:* CIV ENV 216
  - *Materials science and engineering:* MAT SCI 201
  - *Systems engineering and analysis:* IEMS 326
  - 1 additional course from BMD ENG 220, 250, 270, 271; CHEM 342-1; CHEM ENG 210, 211, 312, 321; CIV ENV 219, 304, 306; EECS 205, 211, 221, 222, 223, 224, 230, 231, 270, 302 317, 328; ES APPM 346; IEMS 303, 310, 313; MAT SCI 203, 301, 314, 315; MECH ENG 220, 233, 241, 359, 370
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 10 core courses: DSGN 308 *or* MECH ENG 315; DSGN 344; IEMS 201 *or* 303, 305 *or* 307, 310, 382; MAT SCI 318; MECH ENG 240, 340-1; 340-2 or -3
- 2 senior design project courses: DSGN 298, 398
- 4 technical electives: 2 courses from an approved list; 2 300-level engineering courses

Certificate in Engineering Design

This certificate program, administered by the Segal Design Institute, develops a set of design skills that prove valuable in careers across the entire spectrum available to McCormick graduates. The program focuses on innovative engineering design in team-based, cross-disciplinary settings that address real-world problems.

Certificate Requirements (6 units)

- 3 required courses: DSGN 298, 370, 398
- 3 elective courses from an approved list
- An engineering design portfolio demonstrating accomplishments in prototyping and implementation, modern software tools, design analysis, writing, project management, and effective graphical communication
- Successful completion of a Northwestern baccalaureate degree

Courses

DSGN 106-1,2 Engineering Design and Communication (.5 unit each) See General Engineering Courses.

DSGN 245-1,2 Computer-Aided Design I, II (.5 unit each) **1.** Introduction to CAD software. Students develop solid models, detail drawings, and product assemblies. **2.** Building more complex shapes such as splines and other developed curves, building sheets through one or more sets of curves, and applying specially shaped transitions between faces. This sequence may not be repeated for credit.

DSGN 295-0 Introductory Topics in Design Topics suggested by students or faculty members and approved by the institute; taught at an intermediate level.

DSGN 297-0 Intermediate Topics in Engineering Design (.5 unit) Topics suggested by students and faculty and approved by the institute.

DSGN 298-0 Interdisciplinary Design Projects I Product or system design projects carried out by small student groups.

Conceptual and detailed design, implementation and evaluation, reporting and archiving. Prerequisite: 106-1,2.

DSGN 307-0 Introduction to Industrial Design Methods The process of product development from an industrial design perspective.

DSGN 308-0 Human-Centered Product Design Project-based course focusing on user needs: observational methods, brainstorming, prototyping, business models, and the social and engineering concerns for product design. Prerequisite: sophomore standing or 106-1,2.

DSGN 344-0 Manufacturing Engineering Design Production-system design with emphasis on manual assembly, machining processes, material handling and storage, and product design for manufacture and assembly. Prerequisite: MECH ENG 340-1 or consent of instructor.

DSGN 350-0 Innovation and Invention This course aims to help engineering students understand their critical role in the invention/creative process and to yield insight on the technologist's role in wealth creation. Prerequisite: senior standing or consent of instructor.

DSGN 360-0 Design Competition Undergraduate teams compete in McCormick's annual autonomous robot contest. Work begins winter quarter; teams must pass a qualifying milestone to register for credit in spring quarter. Students may register for this course no more than two times.

DSGN 370-0 Engineering Design Portfolio and Presentation Students create portfolios that showcase engineering work and further career goals. The portfolio is a design project aimed at presenting a story about its creator in a physical presentation that embodies its goals.

DSGN 371-0 Communicating Complex Data (.5 unit) Best practices in creating graphs, tables, and diagrams to communicate complex technical data clearly and powerfully. The course emphasizes the display of complex data as evidence in support of effective arguments.

DSGN 395-0 Special Topics in Design Engineering Topics relevant to design engineering and approved by the institute. Prerequisite: consent of instructor.

DSGN 397-0 Topics in Engineering Design (.5 unit) Topics suggested by students and faculty and approved by the institute.

DSGN 398-0 Interdisciplinary Design Project II Large-scale, open-ended team projects in real-world settings. Integrated, multidisciplinary approach addressing product, process, and systems considerations. Written and oral reports. Prerequisite: senior status or consent of instructor.

DSGN 399-0 Independent Study Independent study on a manufacturing engineering topic supervised by a faculty member. Prerequisite: consent of instructor.

See the Cross-School Options chapter for opportunities open to all Northwestern undergraduates.

MATERIALS SCIENCE AND ENGINEERING

www.matsci.northwestern.edu

Materials science and engineering is a discipline that has expanded rapidly in response to growing demand for materials that make improved use of existing resources or are needed for new technologies. The program at Northwestern is broad based, offering educational and research opportunities in polymer science, ceramics, metallurgy, surface science, biomaterials, nanomaterials, and electronic materials. Engineers, scientists, and technologists who work on these different materials all apply basically the same scientific principles governing the interrelation of processing, structure, properties, and material performance. A key theme of the Northwestern program is the integration of these principles in the systematic design of new materials.

The department offers an undergraduate program leading to the BS degree. The department also participates in the co-op and BS/MS programs. The curriculum centers on basic engineering and materials course work but also provides the flexibility to focus on different areas of concentration as described below. A student's educational experience is broadened by courses in the humanities, arts, sciences, and other areas of engineering. The undergraduate program culminates in the senior project, in which each student carries out a research/development project with a faculty member and his or her research group.

Students who complete the BS program will be well prepared for professional work or graduate study in the application, production, processing, or research and development of materials. Graduates find opportunities in materials science and engineering in many other areas, since materials expertise is important in various engineering fields as well as in medicine, physics, and chemistry.

Areas of Concentration

The undergraduate program at Northwestern offers a close relationship between students and faculty. Every effort is made to tailor specific programs to needs and interests. Several broad areas of concentration are described below. Students are encouraged to create other areas that fit particular interests.

Biomaterials

The growth of biotechnology has stimulated interest in the interface of the life sciences and materials science. The field of biomaterials spans three broad areas: biomedical implant materials to replace natural structures; biomimetic materials applying biological concepts to the design of new engineering materials; and application of materials science principles to the understanding of structure and function in biological systems.

Design and Manufacturing

Engineers in industry typically work in teams on projects requiring experience with design and manufacturing. This concentration is meant for students desiring additional strength in these areas and is especially appropriate for those planning a career in industry. It builds on the design content in the materials science curriculum and provides additional interdisciplinary design experience. The concentration also provides industrially relevant strengths in the areas of materials selection, computational tools, materials processing, and failure analysis.

Electronic Materials

As microelectronics enters the era of ultralarge-scale integration, materials scientists face new challenges in developing materials and processes for integrated circuits with components of nanometer dimensions. New scientific principles, materials fabrication techniques, and improved instrumentation will be needed to exploit electronic-level structure/property relations in these devices and their components. New electronic materials must be developed to meet requirements in a growing range of application areas such as spintronics, optical computing, and fuel cells.

Metals and Ceramics

The ability to design increasingly higher-strength alloys allows for lighter structures, and higher-temperature materials provide energy efficiency. Heat-treatable and toughened ceramics exploit advanced knowledge of solid-state phase transformations and reactions. Exciting developments are taking place in high-performance composite combinations of these and other materials for structural and electronic applications.

Nanomaterials

The area of nanomaterials, focusing on materials with feature sizes in the range of 1 to 100 nanometers, is an important research topic that will become increasingly emphasized as nanotechnology industries develop. Examples of nanomaterials include new ultrahigh-strength materials with nanometer-range structural features and new structures designed and self-assembled atom by atom or molecule by molecule. Machines smaller than the tip of a pin can be built using either semiconductor materials processing or biologically inspired processing technology. This specialization is designed to give students the knowledge needed to work at the nanoscale, including design and synthesis, characterization, and theory/modeling/simulation of nanomaterials.

Polymeric Materials

Synthetic polymers offer the engineering community an ever-expanding array of materials having properties that are tailored by chemical and physical processing. New developments are opening up applications for polymers as high-strength, low-weight materials; optoelectronic components; and key materials in other revolutionary areas. The basic understanding of engineering properties in terms of multilevel microstructure is essential for the full utilization of polymers.

Surface Science

A solid communicates with the outside world through its surface. Wear, corrosion, and passivation are well-known surface processes. Chemical, electronic, and mechanical properties of materials depend critically on composition at surfaces and grain boundaries (internal surfaces), surface treatments, and the environment. The surface scientist must be able to not only determine the properties of surfaces or interfaces but also to control them.

Laboratories and Facilities

Materials science and engineering demands sophisticated experimental techniques for the preparation and characterization of advanced materials. The undergraduate program makes heavy use of state-of-the-art laboratory facilities in core courses, technical electives, and senior projects.

Materials preparation and processing equipment is available for all classes of materials, including an advanced crystal growth facility in a clean room environment for preparing single crystals of metals, oxides, alkali halides, and semiconductors. Investigation of complex microstructures employs a wide array of microscopy, diffraction, and microanalysis techniques. This features a unique combination of instruments (cold field–emission transmission electron microscope, atom-probe field-ion microscopes, scanning tunneling microscopes), providing atomic resolution imaging and chemical analysis, complemented by an extensive surface analytical laboratory. Characterization of material properties employs an advanced mechanical testing facility featuring static and dynamic loading under controlled temperature and environment. Specialized facilities measure electrical, spectroscopic, magnetic, and photonic properties. Computer laboratories and a design studio address thermodynamic modeling and simulation of microstructural evolution, with application in materials design.

Degree in Materials Science and Engineering Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses
  - PHYSICS 135-2,3
  - CHEM 101 and 103 *or* CHEM 171 and 172
- 3 design and communications courses
- 5 basic engineering courses
  - *Fluids and solids:* CIV ENV 216
  - *Materials science and engineering:* MAT SCI 301

- ◦ *Thermodynamics:* MAT SCI 314, 315
- ◦ 1 course from BMD ENG 220; CHEM ENG 210, 312; CIV ENV 304, 306; EECS 202, 203, 205, 211, 221, 222, 223, 224, 230, 231, 270, 302, 328, 317; ES APPM 346; IEMS 201, 303, 310, 313, 326; MECH ENG 233, 359
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)

- 11 required courses: MAT SCI 316-1,2, 331, 332, 351-1,2, 361, 390, 391, 396-1,2
- 5 technical electives
  - 5 courses in engineering, natural sciences (usually chemistry or physics), and mathematics chosen to fulfill an area of concentration
  - No more than 2 of the 5 units may be 200-level courses
  - At least 2 of the 5 must be 300-level materials science and engineering courses
  - Examples of programs for concentrations in biomaterials, design and manufacturing, electronic materials, metals and ceramics, nanomaterials, polymeric materials, and surface science are described in a departmental manual for degree candidates.
  - No more than 1 unit of 399 may be counted.

Courses

MAT SCI 101-0 Modern Materials and Society Introduction to materials—how they function, how they are made, the devices they enable, and their impact on society. Role of materials developments in technological innovation and global competitiveness. Prerequisites: high school mathematics and science background. Fulfills Weinberg College distribution requirements; not intended for engineering students.

MAT SCI 190-0 Materials Science and Engineering Freshman Projects Laboratory-oriented, with research projects emphasizing use of the scanning electron microscope and other modern apparatus; correlation of structure with other properties of materials. Lectures, laboratory.

MAT SCI 201-0 Introduction to Materials Introduction to atomic and molecular organization in solids, with emphasis on structure-property relations in ceramics, electronic materials, metals, and polymers. Not to be taken for credit with or after 203 or 301. Prerequisite: CHEM 102.

MAT SCI 301-0 Materials Science Principles Equilibrium and nonequilibrium development of microstructures. Mechanical behavior of metals, ceramics, and polymers. Corrosion and stability of engineering materials. Materials processing. Not to be taken for credit with or after 201 or 203. Prerequisite: CHEM 102.

MAT SCI 314-0 Thermodynamics of Materials Classical and statistical thermodynamics; entropy and energy functions in liquid and solid solutions, and their applications to phase equilibria. Lectures, problem solving. Materials science and engineering degree candidates cannot take this course for credit with or after CHEM 342-1.

MAT SCI 315-0 Phase Equilibria and Diffusion in Materials Application of thermodynamics to ternary phase equilibria. Defects and diffusion in solids. Interdiffusion. Short-circuit diffusion. Defects and transport in ionic solids. Lectures, problem solving. Prerequisite: 314 or equivalent.

MAT SCI 316-1,2 Microstructural Dynamics Principles underlying development of microstructures. Defects, diffusion, phase transformations, nucleation and growth, thermal and mechanical treatment of materials. Lectures, laboratory. Prerequisite: 315 or equivalent.

MAT SCI 318-0 Materials Selection Methods of specifying materials and the processes for making them in the context of a given application. Service performance of materials based on their physical and chemical properties. Case studies and use of high-level databases. Prerequisite: 201.

MAT SCI 331-0 Soft Materials Different kinds of polymeric materials. Relationships between structure and physical properties; rubber elasticity, the glassy state, crystallinity in polymers. Lectures, laboratory. Prerequisites: 301 or equivalent; 314 or CHEM 342-1.

MAT SCI 332-0 Mechanical Behavior of Solids Plastic deformation and fracture of metals, ceramics, and polymeric materials; structure/property relations. Role of imperfections, state of stress, temperatures, strain rate. Lectures, laboratory. Prerequisites: 316-1,2; 316-2 may be taken concurrently.

MAT SCI 333-0 Composite Materials Introduction to ceramic-, metal-, polymer-matrix composites for structural applications. Emphasis on structure (reinforcements, architecture), properties (elasticity, strength, toughness, creep), processing, role of interface. Prerequisites: 316-1,2, 332.

MAT SCI 336-0 Chemical Synthesis of Materials The design of materials targeting important properties through processes that break and form primary chemical bonds. Fundamental principles and main methodologies, including polymerization, biosynthesis, self-assembly, sol-gel reactions, synthesis of nanomaterials, vapor phase synthesis, and composite synthesis. Prerequisite: junior standing in materials science and engineering or consent of instructor.

MAT SCI 337-0 Conducting Polymers Fundamentals and applications of conducting polymers. Hands-on experience in synthesizing conducting polymer nanostructures.

MAT SCI 340-0 Ceramic Processing Steps in production of fired ceramic articles. Powder preparation and characterization, compact formation, slip casting, extrusion and injection molding; firing, liquid-phase and solid-state sintering. Lectures, laboratory. Prerequisite: 316-1 or equivalent.

MAT SCI 341-0 Introduction to Modern Ceramics Applications of ceramic materials, with emphasis on structure (bond, crystal, glass, defect, micro-); properties (thermal, electrical, optical, magnetic, mechanical); and processing (powders, forming, densification). Prerequisites: 316-1,2 or consent of instructor.

MAT SCI 351-1,2 Introductory Physics of Materials Quantum mechanics; applications to materials and engineering. Band structures and cohesive energy; thermal behavior; electrical conduction; semiconductors; amorphous semiconductors; magnetic behavior of materials; liquid crystals. Lectures, laboratory, problem solving. Prerequisites: GEN ENG 205-4 or equivalent; PHYSICS 135-2,3.

MAT SCI 355-0 Electronic Materials Principles, models, and characterization of semiconductor materials. Crystal growth and doping. Diffusion, epitaxy, and monolithic processes. Current transport, nonequilibrium processes, thin films, low-mobility materials, and interfaces. Prerequisite: 316-1 or consent of instructor.

MAT SCI 360-0 Introduction to Electron Microscopy Theories and practice involved in application of scanning electron microscopy and transmission electron microscopy. Lectures, laboratory. Primarily for undergraduates and for graduate students in other departments. Prerequisites: 301; PHYSICS 135-2,3 or equivalent.

MAT SCI 361-0 Crystallography and Diffraction Elementary crystallography. Basic diffraction theory; reciprocal space. Applications to structure analysis, preferred orientation. Film and counter techniques. Lectures, laboratory. Prerequisites: GEN ENG 205-4; PHYSICS 135-2,3.

MAT SCI 362-0 Point, Line, and Planar Imperfections Introduction to point defects, dislocations, and internal interfaces in crystalline solids. Interactions among point, line, and planar imperfections. Metals, ionic solids, semiconductors. Prerequisite: 315.

MAT SCI 370-0 Biomaterials Introduction to biomaterials from a materials science perspective, focusing on synthesis, structure, and properties. Materials used for human repair (permanent implants, devices, materials for drug delivery, tissue-engineering scaffolds); naturally occurring and engineered materials synthesized through biotechnology; biomimetic materials that copy microstructures from nature.

MAT SCI 371-0 Biominerals: Hierarchical Architecture and Function Living organisms use mineral-organic composites in many critical applications: locomotion (bones), defense (shells), and sensing (light, acceleration, magnetic fields). This course considers how biologically based processing of these materials inspires new approaches to materials synthesis.

MAT SCI 376-0 Nanomaterials Introduction to structure-property relationships of materials processed at the nanometer scale. This highly interdisciplinary course is appropriate for undergraduate and graduate students in other departments. Prerequisite: 351-1 or consent of instructor.

MAT SCI 380-0 Introduction to Surface Science and Spectroscopy Surface spectroscopy, including Auger spectroscopy, photoemission, and LEED. Surface dynamics and thermodynamics. Electronic properties of surfaces and interfaces. Gas-surface interactions. Prerequisite: 351-1 or equivalent.

MAT SCI 381-0 Materials for Energy-Efficient Technology A materials-science approach to the challenges of energy-efficient technology: energy content of materials; advanced materials for energy harvesting, transmission, storage, and conversion; materials for energy-efficient transportation and housing. Term paper and oral presentation. Prerequisite: 201, 301, or consent of instructor.

MAT SCI 390-0 Materials Design Analysis and control of microstructures. Quantitative process/structure/property/performance relations with case studies. Computer lab for modeling multicomponent thermodynamics and transformation kinetics. Prerequisites: 315, 316-1,2, or consent of instructor.

MAT SCI 391-0 Process Design Processing of materials. Design and analysis of experiments to identify and optimize key parameters to control properties and performance. Resolving conflicting requirements. Statistical process control.

MAT SCI 394-0 Honors Project in Materials Science Independent study and/or research linked to 396. Comprehensive report on a specific area of modern materials science and engineering. Prerequisite: registration in department honors program.

MAT SCI 395-0 Special Topics in Materials Science and Engineering Topics suggested by students or faculty and approved by the department.

MAT SCI 396-1,2 Senior Project in Materials Science and Engineering To be taken in two consecutive quarters. Independent basic or applied research project, conceived and performed under the direction of a department faculty member. Prerequisite: senior standing in materials science program.

MAT SCI 398-0 Introduction to Plasma Science and Processing Technology Plasma production, plasma properties (microscopic and macroscopic); plasma characterization, transport phenomena, plasma processing of powders and advanced materials.

MAT SCI 399-0 Special Problems in Materials Science Individual problems, including library and design work; comprehensive report on a specific phase of modern materials science. Credit to be arranged.

MECHANICAL ENGINEERING

www.mech.northwestern.edu

The Department of Mechanical Engineering offers a broad range of programs leading to the bachelor of science degree in mechanical engineering.

Mechanical engineering has always meant engines and machinery, but the character of modern engines and machinery has changed enormously because of the ever-increasing demands of performance, compactness, reliability, and productivity. The early devices were built by ingenious mechanics, individuals who possessed the know-how to reduce these ideas to practice. Today, traditional know-how and creative ability are as necessary as ever but no longer sufficient in an increasingly competitive world. It has become necessary to also know why things occur and thus to be able to exert the proper guidance at the earliest stages of planning. Furthermore, in a world of finite resources and in a society increasingly aware of its environment, mechanical engineers must cope with not only the traditional concerns of efficiency and safety but also the undesirable effects of pollution. Clearly, the tools that future mechanical engineers need to possess must be more sophisticated to allow the important but ever-subtle effects to be recognized and controlled.

Mechanical engineering plays a dominant role in a wide spectrum of industries, among them the transportation industry (automotive, rail, air, and marine), heavy machinery (machines producing other machines), the power industry, the environmental industry (heating, ventilation, and air-conditioning), robotics, the light precision-machine enterprises (optical, prosthetic devices, mechanical instruments, and the like), and numerous commercial product industries. Preparation for a career in mechanical engineering requires a basic understanding of the mathematical, physical, and engineering principles essential to planning, designing, and manufacturing new equipment.

The curriculum in mechanical engineering provides a broad fundamental education preparing students for direct entry into industry as well as further professional study. The first part of the curriculum is devoted to mathematics, physics, and chemistry. With this background, fundamental mechanical engineering subjects are studied. These include dynamics, solid mechanics, fluid mechanics, and thermodynamics followed by specialized subjects such as manufacturing, heat transfer, and automatic control. During the final two years, design courses, laboratory courses, and project courses allow students to acquire a taste for the complex task of designing, analyzing, and building a piece of "hardware." In particular, students become aware of the relationships among conceptual design, subsequent analysis (mathematical modeling), manufacturing, systematic experimentation, and final testing. Supporting courses in allied fields of science and engineering broaden the technical proficiency of mechanical engineering, while the elective courses in social sciences, fine arts, history, and philosophy enlarge their background in the problems of humanity.

Elective Concentrations

The program in mechanical engineering is designed to appeal to students with a wide variety of interests and professional goals. By choosing the 5 required elective courses wisely, students can develop a highly personalized curriculum. Some areas of concentration are computer-aided design/computer-aided manufacturing, fluid mechanics, robotics, systems and control, and tribology. In addition, there are special concentrations: biomedical engineering, design, energy, intelligent mechanical systems, manufacturing, nanotechnology/MEMS, and solid mechanics.

The biomedical engineering concentration is open to students interested in the biological and medical applications of mechanical engineering procedures. Students in this concentration can also satisfy the entrance requirements of medical schools.

The design concentration focuses on product design with related conceptual and manufacturing processes.

The energy concentration emphasizes the mechanical aspects of energy conversion and management.

The intelligent mechanical systems concentration focuses on the design of devices featuring mechanical hardware interfaces to electronic hardware and software.

The manufacturing concentration is directed toward planning and selecting manufacturing methods, design for manufacture, computer-aided flexible automation and robotics, and increased efficiency and productivity of current and emerging manufacturing technologies.

The nanotechnology/MEMS concentration focuses on engineering at nanometer- and micrometer-length scales, including properties of materials and design and fabrication of devices.

The solid mechanics concentration focuses on the study of stress and strain in solid bodies, along with the application of computational methods for stress analysis.

A listing of courses that satisfy the elective requirements may be found in the department office.

Facilities

A detailed description of facilities in the reconstructed mechanical engineering laboratories is available in the department office.

Degree in Mechanical Engineering

Requirements (48 units)

Core courses (32 units)

See general requirements on page 198 for details.

- 4 mathematics courses
- 4 engineering analysis and computer proficiency courses
- 4 basic science courses:
  - PHYSICS 135-2,3
  - 2 courses from CHEM 101, 102, 103, 171, 172, 210-1,2
- 3 design and communications courses
- 5 basic engineering courses
  - *Electrical science:* MECH ENG 233 (students planning to take advanced EECS courses may petition to substitute EECS 221)
  - *Fluids and solids:* CIV ENV 216; MECH ENG 241

  - *Materials science and engineering:* MAT SCI 201
  - *Thermodynamics:* MECH ENG 220 (may not be taken with CHEM 342-1 or CHEM ENG 211)
- 7 social sciences/humanities courses
- 5 unrestricted electives

Major program (16 units)
- 7 required courses: MECH ENG 202, 224, 240, 315, 340-1, 377, 390
- 4 advanced study courses, at least 1 course from each group:
  - *Design:* MECH ENG 340-2, 366, 398
  - *Dynamics/controls:* MECH ENG 314, 363, 391; EECS 360
  - *Mechanics:* MECH ENG 362, 365; CIV ENV 327
  - *Thermofluid science:* MECH ENG 370, 373
- 5 electives
  - 2 300-level mechanical engineering courses
  - 1 200- or 300-level technical elective
  - 2 300-level technical electives
  - At least 1 unit must be in mathematics or basic sciences: it may be chosen from IEMS 201 or 202; 200- or 300-level courses in biological sciences, chemistry, earth and planetary sciences, or physics and astronomy; or 300-level courses in mathematics, applied mathematics, or statistics (*Exceptions:* BIOL SCI 307, CHEM 393, PHYSICS 301).
  - No more than 2 units of 399 are allowed.
  - Students are encouraged to concentrate electives in areas of interest. A list of seven areas of concentration, including appropriate courses and descriptions, is available from the department office.

Courses

MECH ENG 201-0 Mechanics I Equivalent force systems. Equilibrium of rigid bodies. Distributed forces and centers of gravity. Kinematics of rigid bodies in planar motion. Prerequisites: PHYSICS 135-1; concurrent registration in MATH 234.

MECH ENG 202-0 Mechanics II Dry friction. Kinetics of rigid bodies in planar motion. Kinetics of particles. Moments of inertia of rigid bodies. Prerequisite: GEN ENG 205-4.

MECH ENG 220-0 Thermodynamics I Basic definitions; Zeroth Law and the meaning of temperature; the First Law applied to flow and nonflow processes; the Second Law and its applications; properties of pure substances; equations of state, the Third Law of Thermodynamics, and introduction to cycles. Prerequisites: GEN ENG 205-3; concurrent registration in MATH 234.

MECH ENG 224-0 Experimental Engineering I Modern electronics; analog and digital circuit construction and conversion. Modern data acquisition involving temperature measurements, control of stepper motors, transient heat transfer, fluid mechanics, deformation of beams. Prerequisites: 220 and 241; 233 or EECS 270; 262 or CIV ENV 216.

MECH ENG 233-0 Electronics Design Design and prototyping of analog and digital electronic circuits using semiconductor devices: diodes, transistors, op amps, logic chips, etc. Optical and other sensors, power electronics, filters, and feedback control. Intended for engineers in all disciplines. Extensive hands-on construction and debugging.

MECH ENG 240-0 Introduction to Mechanical Design and Manufacturing Introduction to strategy and methods of designing, manufacturing, and testing of mechanical products. Material properties and selection methodology, engineering drawing and CAD, and simple manufacturing processes. Prerequisite: MAT SCI 201; CIV ENV 216.

MECH ENG 241-0 Fluid Mechanics I Fundamentals of fluid mechanics. Properties and statics of fluids. Kinematics and dynamics of fluid motion—continuity, momentum, and energy equations. Dimensional analysis, flow in closed conduits. Prerequisites: GEN ENG 205-4.

MECH ENG 260-0 Mechanics of Sports Applications of mechanics and mathematical modeling to sports: baseball, basketball, golf, soccer, swimming, running, and others. Introduction to the biomechanics of sports. Prerequisites: GEN ENG 205-2; MATH 230; or high school physics and consent of instructor.

MECH ENG 262-0 Stress Analysis and Finite Elements I Analytical and numerical methods for study of strains, stresses, and deformations in solids, with applications to design of mechanical components subjected to static and repeated loads. Prerequisite: GEN ENG 205-3.

MECH ENG 314-0 Theory of Machines—Dynamics Three-dimensional kinematics: rotation axes and mechanism analysis, rotation matrices and Euler's angles for rigid bodies. Three-dimensional kinetics: dynamics of particles, central force problems, dynamics of rigid bodies, rotational inertia matrices and principal axes, dynamics of mechanisms, the gyroscope and other torque-free problems. Prerequisite: 202.

MECH ENG 315-0 Theory of Machines—Design of Elements Factors influencing the proportioning of machine elements —stresses, deformations, and failure criteria as applied to shafts, springs, belts, bearings, gears. Lectures, laboratory. Prerequisite: MAT SCI 201; CIV ENV 216.

MECH ENG 316-0 Mechanical Systems Design Design of mechanical systems such as cams, multibar linkages, and precision machines. Design principles and best practices. Case studies and team-based projects. Prerequisite: 315.

MECH ENG 317-0 Molecular Modeling and the Interface to Micromechanics Introduction to modern computational methods for calculating thermodynamic, transport, and structural properties of materials. Computational chemistry, molecular simulation, and mesoscopic methods, with emphasis on tribology applications.

MECH ENG 318-0 Multiscale Simulations Introduction to multiscale modeling and simulation methods for studying material interactions in micro- and nanomechanical systems, as well as in electronic packaging. Hands-on exercises using equipment to characterize nanoscale properties and parallel computer codes.

MECH ENG 319-0 Applications of Surface Science to Nanomechanics and Nanotribology Overview of the composition, structure, chemical, and mechanical properties of surfaces and how they affect surfaces mechanically and tribologically.

MECH ENG 320-0 Micro- and Nanomechanical Properties of Surfaces Micro- and nanomechanical interactions between surfaces, fractal nature of surfaces, interfacial forces, principles of micromechanics, characterization of surfaces using atomic-force microscopy, optical interferometry, and nanoindentation.

CIV ENV 327-0 Finite Element Methods in Mechanics See Civil Engineering.

MECH ENG 333-0 Introduction to Mechatronics Introduction to microprocessor-controlled electromechanical systems. Interfacing sensors and actuators to computers, electrical and mechanical prototyping, dissection of a commercial product. Final team project. Prerequisite: 233, EECS 221, or consent of instructor.

MECH ENG 340-1,2,3 Computer-Integrated Manufacturing Use of computers to improve productivity and reduce costs in the manufacture of discrete parts and assemblies. **1.** Manufacturing processes: Analysis and evaluation of process usage in the contemporary manufacturing environment. Prerequisite: 240 or consent of instructor. **2.** CAD/CAM: Geometric modeling, dimensioning systems, tolerances, design for manufacture, programming of machine tools. Prerequisites: 340-1; 262 or CIV ENV 216; or consent of instructor. **3.** Manufacturing automation: sensors, actuators, and computers for automation; principles of computer control; programmable logic controllers; robotic devices; assembly automation. Prerequisite: 340-2 or consent of instructor.

MECH ENG 341-0 Computational Methods for Engineering Design Introduction to a wide range of computational techniques for engineering design. Modeling, simulation, optimization, design software, examples, and projects with emphasis on computational techniques for design- and manufacturing-related applications. Prerequisite: senior standing or consent of instructor.

MECH ENG 342-0 Mechanics of Cutting and Forming Introduction to plasticity theory applications to simple cutting and forming processes. Process analysis and design: force estimation, friction and redundant work effects, temperature-generated defects, and process and equipment limitations. Prerequisites: 262 or CIV ENV 216; senior standing.

MECH ENG 346-0 Introduction to Tribology Fundamentals of surface contact: surface topography, asperity contact, interfacial phenomena. Friction theories and wear mechanisms. Temperatures in sliding contacts. Hydrodynamic, hydrostatic, elastohydrodynamic, and boundary lubrication.

MECH ENG 358-0 Experimental Engineering II Optical metrology. Stress analysis, fluid flows, combustion, dynamics, and control. Use of optical interferometry, anemometers and pitot tubes, accelerometers, and other advanced measurement devices.

MECH ENG 359-0 Reliability Engineering Probability concepts and random variables. Failure rates and reliability testing. Wear-in, wear-out, random failures. Probabilistic treatment of loads, capacity, safety factors. Reliability of redundant and maintained systems. Fault tree analysis. Prerequisite: GEN ENG 205-4.

MECH ENG 362-0 Stress Analysis Theory of elasticity: elastic stability, principle of minimum potential energy, Rayleigh-Ritz methods. Introduction to finite element methods of stress analysis: computer implementation and use of commercial codes. Structural analysis of rods, beams, columns, and plates. Prerequisite: 262 or CIV ENV 216.

MECH ENG 363-0 Mechanical Vibrations Analysis of vibrations in single- and multidegree-of-freedom systems. Free and forced vibrations with various types of damping. Response to steady-state and transient excitations. Prerequisites: 202; GEN ENG 205-4.

MECH ENG 365-0 Finite Elements for Stress Analysis Introduction to the finite-element method for stress analysis, with emphasis on linear elasticity. Computer implementation of finite-element techniques: finite-element code development and modification; use of commercial codes. Prerequisite: 262, MATH 234, or CIV ENV 216.

MECH ENG 366-0 Finite Elements for Design and Optimization Numerical methods for interaction and optimal CAD. Fully stressed design; design sensitivity analysis and descent methods; optimality criteria to automated design. Prerequisites: senior standing; 365 or consent of instructor.

MECH ENG 370-0 Thermodynamics II Elementary classical thermodynamics, application of first and second laws of thermodynamics to power and refrigeration cycles, mixtures and solution, thermodynamic relations, chemical reactions, phase and chemical equilibrium. Prerequisite: 220.

MECH ENG 373-0 Engineering Fluid Mechanics Laminar and turbulent duct flows. Boundary layers and potential flows. Lift and drag forces. Thermodynamics and mechanics of compressible flow. Nozzle flows and choking. Wave motion and shock waves. Applications to fluid machinery. Prerequisite: 220, 241, or equivalent.

MECH ENG 377-0 Heat Transfer Fundamentals of heat transfer by conduction, convection, and radiation. Steady and transient heat conduction in solids. Forced and free convection in fluids. Properties of thermal radiation. Radiation heat transfer between solids. Solar radiation. Prerequisite: 241.

MECH ENG 379-0 Elements of Combustion Engineering Introduction to combustion processes, providing an understanding of flame processes as they relate to efficiency and pollution due to propulsion and power-generating systems. Diffusion and premixed flames, problems of ignition, quenching, flammability limits, and detonation. Prerequisite: senior standing in mechanical engineering or consent of instructor.

MECH ENG 381-0 Introduction to Microelectromechanical Systems (MEMS) Introduction to microelectromechanical devices, with an emphasis on their manufacturing and mechanical behavior. Materials properties, microfabrication technology, mechanical behavior of microstructures, design, and packaging. Case studies on sensors, wireless communications, fluidic systems, microengines, and biological devices. Prerequisites: CIV ENV 216 or consent of instructor.

MECH ENG 382-0 Experiments in Micro- and Nanoscience and Engineering Interdisciplinary topics spanning the physical and biological sciences and engineering. Seven integrated labs in which students acquire hands-on experience in various aspects of micro- and nanoscience and engineering: clean-room microfabrication, flow visualization in microchannels, nanomechanics, AFM and dip-pen nanolithography, multiphysics computational tools, and experimental techniques to evaluate micro- and nanoscale devices. Prerequisites: 381 or consent of instructor.

MECH ENG 385-0 Nanotechnology Manipulation of matter at the nanometer-length scale to produce useful devices and materials. Scientific and engineering properties of nanoscale systems. Emphasis on development of new techniques.

MECH ENG 389-0 Molecular Machines in Biology Introduction to engineering principles that govern cellular activities at the molecular level. Particular emphasis on the dynamics and kinematics of proteins, especially those that are locomotory or force generating. Lectures, team projects, and presentations. Prerequisite: MATH 230 or consent of instructor.

MECH ENG 390-0 Introduction to Dynamic Systems Modeling the dynamic behavior of physical systems. Concepts of causality, dependent and independent storages, and state. Introduction to bond graphs. Generation of state equations; analytical and computer simulation of system behavior. Application to problems of engineering interest. Prerequisite: GEN ENG 205-4.

MECH ENG 391-0 Fundamentals of Control Systems Mathematical modeling of automatic control systems. Open-loop and closed-loop control. Laplace transform techniques and transfer functions. Stability. Root locus technique, Bode plots, Nyquist criterion. Approaches to control system design, including PID and lead-lag compensation. Not to be taken for credit with or after EECS 360. Prerequisite: 390 or consent of instructor.

MECH ENG 395-0 Special Topics in Mechanical Engineering Topics suggested by students or faculty members and approved by the department.

MECH ENG 398-0 Engineering Design Product or system design projects carried out by small student groups. Project definition, conceptual and detailed design, evaluation, and documentation. Prerequisite: senior standing.

MECH ENG 399-0 Projects Special studies to be done under faculty direction. Credit to be arranged.