

# NORTHWESTERN

Undergraduate Catalog 2009–10

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This catalog for the academic year beginning September 1, 2009, contains University regulations and information about the programs and courses offered by the Judd A. and Marjorie Weinberg College of Arts and Sciences, School of Communication, School of Education and Social Policy, Robert R. McCormick School of Engineering and Applied Science, Medill School of Journalism, and Henry and Leigh Bienen School of Music and about cross-school undergraduate programs. Failure to read this catalog does not excuse a student from knowing and complying with its content.

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## Robert R. McCormick School of Engineering and Applied Science

[www.mccormick.northwestern.edu](http://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 Council of the Accreditation Board for Engineering and Technology (ABET), 111 Market Place, Suite 1050, Baltimore, Maryland 21202.

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 1,150 graduate students. It is housed in the Technological Institute complex, which contains more than 1 million square feet of floor area and provides excellent educational and research facilities.

The Seeley G. Mudd Library for Science and Engineering, adjoining the Technological Institute, is an integrated and centralized collection serving engineering, applied mathematics, astronomy, biochemistry, biology, chemistry, and physics. Nearly all of its scholarly journals are available to Northwestern students over the Internet.

## 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.

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 23).

### 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.
- *Basic program*: 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.

### Personal Computers

Northwestern's campus is fully networked and has widespread wireless Internet connectivity. Accordingly, the McCormick faculty has adopted a policy making each engineering undergraduate responsible for his or her own computing hardware and software for basic tasks and connection to the University's computer network. McCormick

maintains a number of public and departmental computing laboratories, but these are used primarily for higher-level or specialized applications.

## 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 senior 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.

Honors students participating in the program must (1) 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 and (2) 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 major 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](http://www.mccormick.northwestern.edu/research).

### **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.

Students receiving financial aid should note the restrictions under Satisfactory Academic Progress and Financial Aid on page 21.

For a description of the program, see page 34 in the Cross-School Options chapter. For information on applying to the program, see page 17.

### *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. The program may be entered no later than the beginning of the sophomore year; admission requires concurrent approval of both the Henry and Leigh Bienen School of Music and McCormick.

For a description of the program, see page 34 in the Cross-School Options chapter. For information on applying to the program, see page 17.

### **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.

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

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### **Certificate in Biotechnology and Biochemical Engineering**

This certificate program 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 include

- 5 core courses in biological science and biochemical engineering

- 4 electives providing opportunity for greater depth in both fundamental biology and engineering applications
- 1 quarter of independent study to provide hands-on practical experience with a biotech-related project

A minimum GPA of 2.0 must be maintained in the courses in the certificate program, and successful completion of a McCormick BS degree is 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. The program focuses on innovative engineering design in team-based, cross-disciplinary settings that address real-world problems. In addition to 3 units of required course credit and 3 units of elective credit, students must build a portfolio demonstrating their accomplishments in prototyping and implementation, modern software tools, design analysis, writing, project management, and effective graphical communication. Successful completion of a Northwestern baccalaureate degree is required.

### **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 35 for more information on HPME and page 17 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 major field 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](mailto: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
- Engineers for a Sustainable World
- 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

## PROGRAMS OF STUDY

### McCormick Curriculum Requirements

All curricula leading to the bachelor of science degree in engineering or applied science must have the same basic components — mathematics, engineering analysis and computer proficiency, basic sciences, design and communications, basic engineering, social sciences/humanities, unrestricted electives, and major program. Lists of courses qualifying for these components follow.

The abbreviations used for McCormick departments and major curricula in the listings that follow are  
 BME (biomedical engineering)  
 CHEM ENG (chemical and biological engineering)  
 CIV ENV (civil and environmental engineering)  
 CRDV (career development)  
 DSGN (Segal Design Institute/manufacturing and design engineering)  
 EECS (electrical engineering and computer science)  
 ES APPM (engineering sciences and applied mathematics)  
 GEN ENG (general engineering)  
 IEMS (industrial engineering and management sciences)  
 MAT SCI (materials science and engineering)  
 MECH ENG (mechanical engineering)

#### *Mathematics (4 units)*

MATH 220 Differential Calculus of One-Variable Functions  
 MATH 224 Integral Calculus of One-Variable Functions  
 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)*

GEN ENG 205-1,2,3,4 Engineering Analysis or 206-1,2,3,4 Honors Engineering Analysis

#### *Basic Sciences (4 units)*

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

**Chemistry**

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)***Writing and design**

ENGLISH 106-1,2 Writing in Special Contexts  
 DSGN 106-1,2 Engineering Design and Communication

**Speaking**

GEN CMN 102 Public Speaking, GEN CMN 103  
 Analysis and Performance of Literature, or BME 390-2  
 Biomedical Engineering Design  
 Higher-level courses may satisfy this requirement;  
 they are approved on an individual basis.

*Basic Engineering (5 units)*

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**

BME 270 Fluid Mechanics  
 BME 271 Introduction to Biomechanics

CHEM ENG 321 Fluid Mechanics  
 CIV ENV 216 Mechanics of Materials I  
 CIV ENV 219 Continuum Mechanics I  
 MECH ENG 241 Fluid Mechanics I

**Materials science and engineering**

MAT SCI 201 Introduction to Materials, 203 Micro-  
 structure and Engineering Properties of Materials,  
 or 301 Materials Science Principles

**Probability, statistics, and quality control**

BME 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**

BME 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)*

7 courses, which must be approved in advance by the  
 McCormick Humanities Panel, chosen according to  
 one of two options in the following areas:

- Social and behavioral sciences
- Historical studies and values
- Fine arts, language, and literature

*Option A:* At least 2 courses must be chosen in each area.

Only 3 may be 100-level introductory courses; 3 must  
 be thematically related to provide depth.

*Option B:* 5 of the 7 courses must be clearly thematically  
 related. For breadth, no more than 5 courses may come  
 from a single area.

*Unrestricted Electives (5 units)*

Students may take any credit course in the University to  
 explore or extend technical or nontechnical interests.

*Major Program (16 units)*

Any program of study finds its depth or concentration in the 16 units given to the major program of the curriculum. Each engineering 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.

**Curricula in Majors**

Students must meet not only McCormick curriculum requirements but also the specific requirements for the major curriculum being pursued. The following listings of these curricula present additional information or specifics to be used with the basic curriculum.

Some of the listed curricula contain specializations or options within the curriculum. 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 web site 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](http://www.mccormick.northwestern.edu).

*Applied Mathematics (48 units)*

*Department of Engineering Sciences and Applied Mathematics*  
**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**  
GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**  
PHYSICS 135-2,3

2 additional basic science courses (biological sciences, chemistry, earth and planetary sciences, or astronomy)

**Design and communications (3 units)**

**Basic engineering (5 units)**  
EECS 230 or 231

4 courses from at least three of the following areas:

- Computer architecture and numerical methods
- Electrical science
- Fluids and solids
- Materials science and engineering
- Systems engineering and analysis
- Thermodynamics

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

**Major program (16 units)**

• **Required courses (7 units)**

- ES APPM 311-1,2 Methods of Applied Mathematics
- ES APPM 311-3 Methods of Applied Mathematics: Complex Variables or MATH 325 Complex Variables for Applications
- ES APPM 322 Applied Dynamical Systems
- ES APPM 346 Modeling and Computation in Science and Engineering
- ES APPM 421-1 Models in Applied Mathematics
- 1 modeling course from an approved list

• **Additional courses (3 units)**

- MATH 334 Linear Algebra: Second Course
- 2 courses chosen from EECS 302; IEMS 202, 303, 310, 313; MATH 330-1,2,3

• **Engineering or the sciences (4 units)**

- 4 courses 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

• **Technical electives (2 units)**

- 2 courses at the 300 level or higher in engineering, science, or mathematics

*Biomedical Engineering (48 units)*

*Department of Biomedical Engineering*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**  
GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**  
PHYSICS 135-2,3

CHEM 102 and 103 or 171 and 172

**Design and communications (3 units)**

ENGLISH 106-1,2

DSGN 106-1,2

BME 390-2

**Basic engineering (5 units)**

*Fluids and solids:* BME 270 and 271

*Materials science and engineering:* MAT SCI 201 or 301

*Probability, statistics, and quality control:* BME 220;

IEMS 201, 303; or MECH ENG 359

*Thermodynamics:* BME 250; CHEM 342-1; or MECH ENG 220

**Social sciences/humanities (7 units)****Unrestricted electives (5 units)****Major program (16 units)**

The major program consists of 16 courses at the 200 level or higher, none of which may be taken P/N.

- BME 101 Introduction to Biomedical Engineering (noncredit)
- **Core (9 units)**  
BIOL SCI 210-2 Biochemistry and Molecular Biology  
CHEM 210-1 Organic Chemistry  
BME 301, 302, 303 Systems Physiology  
BME 305 Biomedical Signals Analysis  
BME 306 Biomedical Systems Analysis  
BME 307 Quantitative Experimentation and Design  
BME 390-1 Biomedical Engineering Design
- **Areas of specialization (7 units)**

Students select 5 courses 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

The 2 additional technical electives may include BIOL SCI 210-1,3; CHEM 101, 210-3; 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.

*Chemical Engineering (48 units)*

*Department of Chemical and Biological Engineering*

**Mathematics (4 units)****Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2,3

CHEM 102 and 103 or 171 and 172

**Design and communications (3 units)****Basic engineering (5 units)**

*Fluids and solids:* CHEM ENG 321

*Materials science and engineering:* MAT SCI 301

*Probability, statistics, and quality control:* CHEM ENG 312; IEMS 201, 303; or BME 220

*Systems engineering and analysis:* CHEM ENG 210

*Thermodynamics:* CHEM ENG 211

**Social sciences/humanities (7 units)****Unrestricted electives (5 units)****Major program (16 units)**

- **Required courses (12 units)**  
CHEM 210-1,2 Organic Chemistry  
CHEM 342-2 Quantum Mechanics and Spectroscopy

CHEM ENG 212 Phase Equilibrium and Staged Separations

CHEM ENG 275 Molecular and Cell Biology for Engineers (BIOL SCI 210-2 may substitute)

CHEM ENG 307 Kinetics and Reactor Engineering

CHEM ENG 322 Heat Transfer

CHEM ENG 323 Mass Transfer

CHEM ENG 341 Process Dynamics and Control

CHEM ENG 342 Chemical Engineering Laboratory

CHEM ENG 351 Process Economics, Design, and Evaluation

CHEM ENG 352 Chemical Engineering Design Projects

- **Areas of specialization (4 units)**

The remaining 4 units are chosen from advanced engineering, mathematics, or science courses. They must be selected to fulfill one of the six areas of specialization offered by the department:

- Biomedical engineering
- Biotechnology
- Chemical process engineering
- Environmental engineering
- General chemical engineering
- Polymer science and engineering

At least 1 of these courses must be an approved 200- or 300-level science elective.

*Civil Engineering (48 units)*

*Department of Civil and Environmental Engineering*

**Mathematics (4 units)****Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2

CHEM 101, 102

CHEM 103 or PHYSICS 135-3

**Design and communications (3 units)****Basic engineering (5 units)**

*Electrical science:* 1 course

*Fluids and solids:* CIV ENV 216; MECH ENG 241

*Thermodynamics:* 1 course in systems engineering and analysis, computer architecture and numerical methods, computer programming, or materials science

**Social sciences/humanities (7 units)****Unrestricted electives (5 units)****Major program (16 units)**

The major program consist of 16 courses, 10 of which must be civil engineering.

- **Basic civil engineering (7 units)**

CIV ENV 221 Theory of Structures I

CIV ENV 222 Structural Steel Design

CIV ENV 250 Introductory Soil Mechanics

CIV ENV 260 Fundamentals of Environmental Engineering

CIV ENV 330 Construction Management  
 CIV ENV 340 Fluid Mechanics II  
 CIV ENV 371 Introduction to Transportation Planning and Analysis or 376 Transportation System Operations

• **Mathematical techniques and science (2 units)**

2 courses chosen from an approved list, 1 of which must be a calculus-based probability and statistics course

• **Technical electives (7 units)**

7 courses at the 200 level or higher in mathematics, science, engineering, or another area supporting their specialty; 2 must be chosen from an approved list of design and synthesis courses, and 1 of those 2 must be the currently designated “capstone design course”

Listed below 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.

- Applied mechanics
- Construction
- Environmental engineering
- Geotechnical engineering
- Structural engineering
- Transportation systems

*Computer Engineering (48 units)*

*Department of Electrical Engineering and Computer Science*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2,3

2 units from biological sciences, chemistry, or earth and planetary sciences/astronomy

**Design and communications (3 units)**

**Basic engineering (5 units)**

*Computer architecture and numerical methods:* EECS 203 (grade of C– or better required for graduation).

*Computer programming:* EECS 231

*Electrical science:* EECS 202 (grade of C– or better required for graduation)

*Probability, statistics, and quality control:* EECS 302

1 course in fluids and solids, materials science, systems engineering and analysis, or thermodynamics

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

**Major program (16 units)**

• **Required courses (5 units)**

EECS 205 Fundamentals of Computer System Software

EECS 221 Fundamentals of Circuits

EECS 303 Advanced Digital Logic Design

EECS 311 Data Structures and Data Management

EECS 361 Computer Architecture

• **Technical electives (10 units)**

Technical electives may be used to tailor a program to a particular area of specialization. Students must take at least

5 units from the following four tracks and 2 units from the fundamental electrical engineering courses listed below.

The remaining 3 electives 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. 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.

*Embedded systems track*

EECS 332 Digital Image Analysis

EECS 346 Microprocessor System Design

EECS 347-1 Microprocessor System Projects I

EECS 347-2 Microprocessor System Projects II

EECS 390 Introduction to Robotics

BME 384 Biomedical Computing

*Fundamental electrical engineering courses*

EECS 213 Introduction to Computer Systems

EECS 222 Fundamentals of Signals and Systems

EECS 223 Fundamentals of Solid-State Engineering

EECS 224 Fundamentals of Electromagnetics and

Photonics

EECS 225 Fundamentals of Electronics

*High-performance computing track*

EECS 328 Numerical Methods for Engineers

EECS 333 Introduction to Communication Networks

EECS 358 Introduction to Parallel Computing

EECS 362 Computer Architecture Project

*Software track*

EECS 310 Mathematical Foundations of

Computer Science

EECS 322 Compiler Construction

EECS 336 Design and Analysis of Algorithms

EECS 339 Introduction to Database Systems

EECS 394 Software Project Management and

Development

*VLSI and CAD track*

EECS 353 Digital Microelectronics

EECS 357 Introduction to VLSI CAD

EECS 391 VLSI Systems Design

EECS 392 VLSI Systems Design Projects

• **Design requirement (1 unit)**

1 course chosen from

EECS 347-1 Microprocessor System Projects I

EECS 362 Computer Architecture Project

EECS 392 VLSI Systems Design Projects

*Computer Science (48 units)*

*Department of Electrical Engineering and Computer Science*

**Mathematics (4 units)**

MATH 220, 224, 230

EECS 310

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3

EECS 111

**Basic sciences (4 units)****Design and communications (3 units)****Basic engineering (5 units)**

*Computer programming:* EECS 211

*Probability, statistics, and quality control:* IEMS 201, 303 or EECS 302

3 other basic engineering courses, excluding computer science

**Social sciences/humanities (7 units)****Unrestricted electives (5 units)****Major program (16 units)**• **Required courses (3 units)**

EECS 101 An Introduction to Computer Science for Everyone

EECS 213 Introduction to Computer Systems

EECS 311 Data Structures and Data Management

• **Technical electives (13 units)**

5 courses chosen from the list of breadth courses (available from the department)

6 courses chosen from the list of depth courses (available from the department)

2 project courses, each resulting in the construction and demonstration of a proposed solution to some organization's problem. Projects must be approved by a faculty adviser beforehand. Project work will typically occur in independent study projects (EECS 399) or in project-oriented courses (e.g., EECS 394). No more than 4 units of EECS 338 may be used for the degree requirements.

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.

*Electrical Engineering (48 units)*

*Department of Electrical Engineering and Computer Science*

**Mathematics (4 units)****Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2,3

2 additional basic science courses

**Design and communications (3 units)****Basic engineering (5 units)**

*Electrical science:* EECS 202 (grade of C- or better required for graduation)

*Computer architecture and numerical methods:* EECS 203 (grade of C- or better required for graduation)

*Computer programming:* EECS 211 or 230

*Probability, statistics, and quality control:* EECS 302

1 other course chosen from fluids and solids, materials science and engineering, systems engineering, or thermodynamics

**Social sciences/humanities (7 units)****Unrestricted electives (5 units)****Major program (16 units)**• **Required courses (5 units)**

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 225 Fundamentals of Electronics

• **Technical electives (10 units)**

Technical electives may be used to tailor a program to a particular area of specialization. Students must take at least 6 courses chosen from the following six tracks and 2 courses from 300-level EECS technical electives (which may include the courses below). The remaining 2 electives 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 below. 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.

*Biomedical engineering track*

BME 317 Biochemical Sensors

BME 325 Introduction to Medical Imaging

BME 327 Magnetic Resonance Imaging

BME 333 Modern Optical Microscopy and Imaging

BME 383 Cardiovascular Instrumentation

*Circuits and electronics track*

EECS 303 Advanced Digital Logic Design

EECS 346 Microprocessor System Design

EECS 353 Digital Microelectronics

EECS 355 ASIC and FPGA Design

EECS 391 VLSI Systems Design

EECS 393 VLSI Design and Analysis of High-Speed Integrated Circuits

*Communications systems track*

EECS 307 Communications Systems

EECS 333 Introduction to Communication Networks

EECS 378 Digital Communications

EECS 380 Wireless Communications

*Control systems track*

EECS 360 Introduction to Feedback Systems or

MECH ENG 391 Fundamentals of Control Systems

EECS 374 Introduction to Digital Control

EECS 390 Introduction to Robotics

MECH ENG 333 Introduction to Mechatronics

*Digital signal processing track*

EECS 332 Digital Image Analysis

EECS 359 Digital Signal Processing

EECS 363 Digital Filtering

*Electromagnetics and optics track*

EECS 308 Advanced Electromagnetics and Photonics

EECS 379 Lasers and Coherent Optics

EECS 382 Photonic Information Processing  
 EECS 383 Fiber-Optic Communications  
 EECS 386 Computational Electromagnetics and Photonics

*Solid-state engineering track*

MECH ENG 381 Introduction to Microelectromechanical Systems (MEMS)

EECS 250 Physical Electronics and Devices  
 EECS 381 Electronic Properties of Materials  
 EECS 384 Solid-State Electronic Devices  
 EECS 385 Optoelectronics  
 EECS 388 Nanotechnology

• **Design requirement (1 unit)**

1 course chosen from  
 EECS 347-1 Microprocessor System Projects I  
 EECS 392 VLSI Systems Design Projects  
 EECS 398 Electrical Engineering Design  
 EECS 399 Projects (when 399 is a design project)

*Environmental Engineering (48 units)*

*Department of Civil and Environmental Engineering*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2  
 CHEM 101, 102, 103

**Design and communications (3 units)**

**Basic engineering (5 units)**

*Computer architecture and numerical methods:* EECS 328  
 or ES APPM 346 or 1 materials science course

*Fluids and solids:* MECH ENG 241

*Probability, statistics, and quality control:* 1 unit  
 (CIV ENV 306 recommended)

*Systems engineering and analysis:* CIV ENV 304 or  
 IEMS 326

*Thermodynamics:* CHEM 342-1

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

**Major program (16 units)**

• **Core (12 units)**

CHEM 210-1 Organic Chemistry  
 CIV ENV 260 Fundamentals of Environmental Engineering  
 CIV ENV 340 Fluid Mechanics II  
 CIV ENV 361 Environmental Microbiology and Public Health  
 CIV ENV 363 Environmental Engineering Applications I: Air and Land  
 CIV ENV 364 Environmental Engineering Applications II: Water  
 CIV ENV 365 Environmental Laboratory  
 CIV ENV 367 Aquatic Chemistry  
 CIV ENV 382 Capstone Design Experience  
 ENVR SCI 201 Earth: A Habitable Planet

ENVR SCI 202 The Health of the Biosphere  
 ENVR SCI 203 Energy and the Environment: The Automobile

• **Technical electives (4 units)**

2 courses from an approved list  
 2 courses, 200 level or higher, in engineering or mathematics or science in Weinberg College

*Industrial Engineering (48 units)*

*Department of Industrial Engineering and Management Sciences*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2 and 1 unit of chemistry recommended

**Design and communications (3 units)**

**Basic engineering (5 units)**

EECS 230  
 EECS 317 or 328  
 IEMS 326  
 2 additional basic engineering courses (excluding IEMS 313)

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

**Major program (16 units)**

• **Probability and statistics (2 units)**

IEMS 202 Probability  
 IEMS 303 Statistics

• **Operations research (3 units)**

IEMS 313 Deterministic Models and Optimization  
 IEMS 315 Stochastic Models and Simulation  
 IEMS 317 Discrete-Event Systems Simulation

• **Applied behavioral science (1 unit)**

IEMS 340 Field Project Methods or  
 342 Organization Behavior

• **Production and logistics (1 unit)**

IEMS 381 Supply-Chain Modeling and Analysis  
 or 382 Production Planning and Scheduling  
 or 383 Service Operations Management

• **Senior design project (2 units)**

IEMS 390 Systems Management, 391 Industrial Engineering Design, or 392 Systems Project Management  
 IEMS 393 Industrial Engineering Design Project

• **Electives (7 units)**

3 industrial engineering/operations courses chosen from  
 IEMS 304 Statistical Methods for Data Mining  
 IEMS 305 Statistical Methods for Quality Improvement  
 IEMS 306 Decision Analysis  
 IEMS 307 Quality Improvement by Experimental Design  
 IEMS 373 Introduction to Financial Engineering  
 IEMS 381 Supply-Chain Modeling and Analysis  
 IEMS 382 Production Planning and Scheduling

IEMS 383 Service Operations Management  
 IEMS 391 Industrial Engineering Design  
 1 management science course chosen from  
 IEMS 325 Engineering Entrepreneurship  
 IEMS 340 Field Project Methods  
 IEMS 341 Social Network Analysis  
 IEMS 342 Organizational Behavior  
 IEMS 390 Systems Management  
 IEMS 392 Systems Project Management  
 3 engineering courses at the 200 level or higher or any  
 course chosen from the general technical elective  
 group (available from the department); no more than  
 2 units of 399 are allowed  
 No more than 2 courses, and only those in the last  
 group, may be taken P/N.

• **Concentration (optional)**

At least 4 courses chosen 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  
 web site.

*Manufacturing and Design Engineering (48 units)*

*Segal Design Institute*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2,3

2 chemistry courses

**Design and communications (3 units)**

**Basic engineering (5 units)**

*Computer architecture and numerical methods or  
 electrical science:* EECS 202 or 203

*Fluids and solids:* CIV ENV 216

*Materials science and engineering:* MAT SCI 201

*Systems engineering and analysis:* IEMS 326

1 additional course

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

**Major program (16 units)**

• **Core (10 units)**

DSGN 308 Human-Centered Product Design or  
 MECH ENG 315 Theory of Machines — Design of  
 Elements

DSGN 344 Manufacturing Engineering Design

IEMS 201 Introduction to Statistics or 303 Statistics I

IEMS 305 Statistical Methods for Quality Improvement  
 or 307 Quality Improvement by Experimental Design

IEMS 310 Operations Research

IEMS 382 Production Planning and Scheduling

MAT SCI 318 Materials Selection

MECH ENG 240 Introduction to Mechanical Design  
 and Manufacturing

MECH ENG 340-1 Computer-Integrated  
 Manufacturing

MECH ENG 340-2 or -3 Computer-Integrated  
 Manufacturing

• **Senior design project (2 units)**

DSGN 398 Interdisciplinary Design Project II  
 1 course chosen from

DSGN 298 Interdisciplinary Design Projects I

IEMS 391 Industrial Engineering Design

MECH ENG 398 Engineering Design

• **Technical electives (4 units)**

2 courses from an approved list and 2 300-level  
 engineering courses

*Materials Science and Engineering (48 units)*

*Department of Materials Science and Engineering*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2,3

CHEM 102 and 103 or 171 and 172

**Design and communications (3 units)**

**Basic engineering (5 units)**

*Fluids and solids:* CIV ENV 216 or 219

*Materials science and engineering:* MAT SCI 301

*Thermodynamics:* MAT SCI 314 and 315

*Elective:* 1 course selected from computer architecture  
 and numerical methods, computer programming,  
 electrical science, probability, statistics, and quality  
 control, or systems engineering and analysis

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

MAT SCI 190 recommended

**Major program (16 units)**

• **Required courses (11 units)**

MAT SCI 316-1,2 Microstructural Dynamics

MAT SCI 331 Soft Materials

MAT SCI 332 Mechanical Behavior of Solids

MAT SCI 351-1,2 Introductory Physics of Materials

MAT SCI 361 Crystallography and Diffraction

MAT SCI 390 Materials Design

MAT SCI 391 Process Design

MAT SCI 396-1,2 Senior Project in Materials Science  
 and Engineering

• **Technical electives (5 units)**

Each student must choose the remaining courses in a  
 consistent manner to fulfill an area of concentration.  
 These courses may be in engineering, natural sciences  
 (usually chemistry or physics), and mathematics. 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 majors.

*Mechanical Engineering (48 units)*

*Department of Mechanical Engineering*

**Mathematics (4 units)**

**Engineering analysis and computer proficiency (4 units)**

GEN ENG 205-1,2,3,4

**Basic sciences (4 units)**

PHYSICS 135-2,3

2 chemistry courses

**Design and communications (3 units)**

**Basic engineering (5 units)**

*Electrical science:* MECH ENG 233 (students planning to take advanced EECS courses may substitute EECS 221)

*Fluids and solids:* CIV ENV 216; MECH ENG 241

*Materials science and engineering:* MAT SCI 201

*Thermodynamics:* MECH ENG 220

**Social sciences/humanities (7 units)**

**Unrestricted electives (5 units)**

**Major program (16 units)**

• **Required courses (7 units)**

MECH ENG 202 Mechanics II

MECH ENG 224 Experimental Engineering I

MECH ENG 240 Introduction to Mechanical Design and Manufacturing

MECH ENG 315 Theory of Machines — Design of Elements

MECH ENG 340-1 Computer-Integrated Manufacturing

MECH ENG 377 Heat Transfer

MECH ENG 390 Introduction to Dynamic Systems

• **Advanced study (4 units)**

At least 1 course from each group:

*Design*

MECH ENG 340-2 Computer-Integrated Manufacturing

MECH ENG 366 Finite Elements for Design and Optimization

MECH ENG 398 Engineering Design

*Dynamics/controls*

MECH ENG 314 Theory of Machines — Dynamics

MECH ENG 363 Mechanical Vibrations

MECH ENG 391 Fundamentals of Control Systems

*Mechanics*

MECH ENG 362 Stress Analysis

MECH ENG 365 Finite Elements for Stress Analysis

CIV ENV 327 Finite Element Methods in Mechanics

*Thermofluid science*

MECH ENG 370 Thermodynamics II

MECH ENG 373 Engineering Fluid Mechanics Design

• **Electives (5 units)**

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.

### 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.

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.

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

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## GENERAL ENGINEERING 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. 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. 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. 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. 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.** 3D 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.

**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.

## BIOMEDICAL ENGINEERING

[www.bme.northwestern.edu](http://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.

## Undergraduate Program

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.

### Areas of Specialization

All areas are suitable for students planning to enter medical school, continue their biomedical engineering education in graduate school, or pursue careers in the biomedical industry or hospitals.

#### *Biological Materials and Molecular Engineering*

Principles from biochemical and materials science engineering, molecular biology, and biosensors are applied to the creation and adaptation of materials for medical applications (e.g., implants, medical-device coatings, drug delivery). Students in this area learn about various aspects of biology and chemistry from the engineer's perspective.

#### *Biomechanics and Rehabilitation*

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. Students in this area learn the fundamental engineering principles needed for this work.

#### *Biomedical Signals and Images*

The application of imaging, signal processing, and signal analysis to biomedical problems has become an important part of medicine. MRI, CT-imaging, PET, EKG, and EEG are all examples of physiological signals. Students in this area learn the physiology that underlies these signals and the engineering that underlies their recording and analysis.

#### *Electronic Instrumentation*

Electronic instruments are used widely 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 (hardware and software) instrumentation.

#### *Transport Processes and Tissue Engineering*

The study of transport processes in living tissue is important in understanding blood flow, lung ventilation, and oxygen transport to and from red blood cells to various tissue beds. Students in this area learn the fundamental chemical engineering principles that relate to these processes.

### Curriculum

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.

### Courses

#### **BME 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 major, possible career and research opportunities, and ethics.

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

**BME 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.

**BME 270-0 Fluid Mechanics** Fundamentals of fluid mechanics and their applications to biological systems.

**BME 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.

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

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

**BME 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.

**BME 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.

**BME 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; BME 305.

**BME 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.

**BME 308-0 Biomedical Engineering Laboratory** Laboratory and associated lecture concerning quantitative physiology, testing, and evaluation of biomedical apparatus. Prerequisites: at least 2 courses chosen from 301, 302, 303. Preference given to seniors in biomedical engineering.

**BME 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.

**BME 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.

**BME 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.

**BME 317-0 Biochemical Sensors** Theory, design, and applications of chemical sensors used in medical diagnosis and patient monitoring. Electrochemical and optical sensors. Prerequisites: chemistry through 210-2; physics through 135-3.

**BME 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.

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

**BME 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.

**BME 333-0 Modern Optical Microscopy and Imaging** Rigorous introduction to principles, current trends,

emerging technologies, and biomedical applications of modern optical microscopy.

**BME 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.

**BME 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.

**BME 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.

**BME 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.

**BME 350-0 Transport Fundamentals** Fundamental and biomedical applications of diffusive and convective heat and mass transfer. Prerequisites: 270; MATH 230; BME 377 recommended.

**BME 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.

**BME 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, BME 271, or consent of instructor.

**BME 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; BME 271.

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

**BME 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.

**BME 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.

**BME 384-0 Biomedical Computing** Principles of modern (computer-based) medical instrumentation, including analog versus digital design tradeoffs, efficient digital filter designs, and algorithms for physiological signal processing, automated event recognition, and classification. Prerequisites: EECS 270 or equivalent and some experience in computer programming, or consent of instructor.

**BME 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.

**BME 395-0 Special Topics in Biomedical Engineering**

**BME 399-0 Projects**

## CHEMICAL ENGINEERING

[www.chem-biol-eng.northwestern.edu](http://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.

#### *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. Process dynamics and automatic control principles are studied in the Process Dynamics and Control Laboratory. A computing laboratory is used in a variety of courses. Chemical laboratory experience is also a part of the polymer course.

### 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: 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 (C- or better); 211.

**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.

**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.

**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.

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

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

**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: 307, 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: senior 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, 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; 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, or BMD ENG 270; 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), 375, 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.

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

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## CIVIL AND ENVIRONMENTAL ENGINEERING

[www.civil.northwestern.edu](http://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.

## **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 contaminants 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.

## **Courses**

**CIV ENV 206-0 Environmental Literacy** Simple concepts from the sciences and engineering applied to specific environmental problems, including the concepts of risk. Understanding of and quantitative facility in multidisciplinary aspects of environmental decisions.

**CIV ENV 212-0 Mechanics** Force systems, equivalence of force systems, and resultants. Equilibrium of a rigid body and systems. Kinematics and dynamics of a rigid body in plane motion. Work and energy relations for a rigid body in plane motion. Prerequisites: PHYSICS 135-1; registration in MATH 234.

**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.

**CIV ENV 222-0 Structural Steel Design** Rational basis of structural design. Design approach for structural steel components of a building system. Prerequisite: 221.

**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 267-0 Chemistry of the Natural Environment** Fundamental principles of organic and inorganic chemistry applied to air, water, soil, and sediments. Focus on problem solving. Laboratory/field projects. Prerequisite: CHEM 103.

**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 307-0 Microstructure of Cement-Based Materials** Chemistry of the principal silicate and aluminate cements used in building and civil and environmental engineering. Emphasis on underlying science rather than on practical application. Experimental and theoretical aspects of cement chemistry; relationships between processing, microstructure, and properties.

**CIV ENV 319-0 Theory of Structures II** Shear center, non-prismatic 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 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 338-0 Public Infrastructure Management** Explores the complexity of managing public infrastructure facilities by means of a five-part interactive model. Aims to impart a realistic appreciation of contemporary policies and practices. Prerequisite: senior standing.

**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 359-0 Hazardous Waste Management** Definition and regulation of wastes. Pollutant transport, fate, and toxicology. Management via audits and prevention. Treatment and control. Risk and site assessment and site remediation. Prerequisite: junior or senior standing in engineering or science or consent of instructor.

**CIV ENV 360-0 Environmental Impact Evaluation** Environmental legislation and quality indices. Methods for evaluating impact of engineering projects on environmental quality. Impact statements, projects, and summary impact reports. Prerequisite: junior standing.

**CIV ENV 361-0 Environmental Microbiology and Public Health** Evaluation of the disease status of a community; elements of vital statistics and epidemiology; etiology of infectious and noninfectious diseases; control of environmentally based health hazards.

**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 366-0 Ecosystems and Ecotoxicology** Terrestrial, freshwater, marine, and estuarine ecosystems. Fundamentals of toxicology and their application to natural environments and biotic components; tolerance limits and adaptation of organisms to environmental change brought on naturally or by human technology and activity. Prerequisite: junior standing in engineering or science.

**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: CHEM 342-1.

**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 369-0 The Industrial Ecology of Materials and Products** A course to increase students's knowledge of ecodesign, green products, environmentally friendly manufacturing, reuse of various materials, and recycling.

**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 Experience** 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 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.

## DESIGN ENGINEERING

[www.segal.northwestern.edu](http://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.

The institute administers

- introductory courses required of all McCormick students (DSGN 106-1,2)
- the bachelor's degree in manufacturing and design engineering
- a certificate in engineering design

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.

### 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.

## ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

[www.eecs.northwestern.edu](http://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, animate arts, cognitive science. It collaborates with Weinberg College to offer the computer science major (see page 80).

Detailed information on degree requirements and elective courses is available from the department office or at [www.eecs.northwestern.edu](http://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 tera-bit 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.

## 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 the field of writing software that runs on compilers. 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 multi-FPGA systems, and CAD techniques.

### 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

### 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 101-0 An Introduction to Computer Science for

**Everyone** General introduction to historical and current intellectual questions in computer science; suitable for majors and nonmajors. 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 computer science majors.

**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 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. Prerequisite: GEN ENG 205-3.

**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 computer science majors. 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; 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 majors. Prerequisites: MATH 224; PHYSICS 135-2; or equivalent.

**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 computer science majors. 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 majors.

**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 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: 303, 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 ASIC and 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<sup>+</sup> (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 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 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-T<sub>c</sub> 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.

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

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## ENGINEERING SCIENCES AND APPLIED MATHEMATICS

[www.esam.northwestern.edu](http://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.

### 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: 252-3; MATH 250; or GEN ENG 205-4.

**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: 252-3; MATH 250; or GEN ENG 205-4.

**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.

## INDUSTRIAL ENGINEERING AND MANAGEMENT SCIENCES

[www.iems.northwestern.edu](http://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 IE 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.

### 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 majors. 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 majors. 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.

**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 nonmajors: 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 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 majors; 310 for manufacturing engineering majors.

**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.

## MATERIALS SCIENCE AND ENGINEERING

[www.matsci.northwestern.edu](http://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.

## **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 majors.

**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. Majors in materials science and engineering 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 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 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 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](http://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.

## 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, elasto-hydrodynamic, 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.

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

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