# COLLEGE OF ENGINEERING

## ADMINISTRATION

W. Kent Fuchs, dean

David Gries, associate dean for undergraduate programs

Christopher K. Ober, associate dean for research and graduate studies

Richard Allmendinger, associate dean for diversity

Deborah Cox, assistant dean for strategic planning, assessment, and new initiatives

Betsy East, assistant dean for student services

Cathy Dove, associate dean for administration

Tim Dougherty, assistant dean for alumni affairs and development

## FACILITIES AND SPECIAL PROGRAMS

Most of the academic units of the College of Engineering are on the Joseph N. Pew, Jr. Engineering Quadrangle. The School of Applied and Engineering Physics is located in Clark Hall on the College of Arts and Sciences campus, and the Department of Biological and Environmental Engineering is in Riley-Robb Hall on the campus of the New York State College of Agriculture and Life Sciences.

Special university and college facilities augment the laboratories operated by the various engineering schools and departments, and special centers, institutes, and programs contribute to opportunities for study and research.

Cornell programs and centers of interest in engineering include the following:

*Alliance for Nanomedical Technologies.* The alliance brings together collaborative teams of academic scientists and industrial affiliates to explore the design and fabrication of novel nanomedical devices.

*Center for Advanced Computing.* CAC is a supercomputer facility used for advanced research in engineering and the physical and biological sciences.

*Center for Applied Mathematics.* This cross-disciplinary center administers a graduate program.

*Center for Nanoscale Systems.* The mission of this National Science Foundation Nanoscience and Technology Center is to develop innovative nanoscale systems to revolutionize information technology and to further nanoscience technology. The facilities for this center are distributed between Clark Hall and the Engineering Quadrangle, and especially in Duffield Hall.

*Center for Radiophysics and Space Research.* This interdisciplinary unit facilitates research in astronomy and the space sciences.

*Cornell Center for the Environment.* The center seeks to catalyze interdisciplinary and multi-institutional research on the environment, connect Cornell's environmental research capacity to needs around the world, and engage Cornell's scientific talent as new issues arise.

*Cornell Center for Materials Research.* CCMR is an interdisciplinary center, with substantial support from the National Science Foundation, that performs state-of-the-art materials research and provides sophisticated scientific measurement and characterization equipment.

*Cornell High Energy Synchrotron Source.* CHESS is a high-energy synchrotron radiation laboratory operated in conjunction with the university's high-energy storage ring. Current research programs at CHESS are in areas of structural biology, chemistry, materials science, and physics.

*Cornell Nanoscale Science and Technology Facility* (part of the National Science Foundation–funded National Nanofabrication Users Network). This center provides equipment and services for research in the science, engineering, and technology of nanometer-scale structures for electronic, chemical, physical, and biological applications.

*Information Assurance Institute.* The institute's activities are aimed at developing a science and technology base to enhance information assurance, reliability, security, and trustworthiness in networked information systems.

*Institute for the Study of the Continents.* This interdisciplinary organization promotes research in deep seismic exploration of the structure, composition, and evolution of the continents.

*Intelligent Information Systems Institute.* IISI seeks to stimulate research in compute- and data-intensive methods for intelligent decision-making systems, to foster collaboration, and to play a leadership role in the research and dissemination results in its core areas.

*Kavli Institute at Cornell for Nanoscale Science.* KIC addresses challenges and opportunities for the science of very small structures and fosters collaborative multidisciplinary research in this area.

*Laboratory of Atomic and Solid State Physics.* This is a major center for research in the area of condensed matter physics and other related areas.

*Laboratory of Plasma Studies.* LPS is a center for research in plasma physics.

*MCEER.* This facility was established by the National Science Foundation and a group of universities to study the response and design of structures in earthquake environments.

*Nanobiotechnology Center.* The mission of this National Science Foundation Science and Technology Center is to develop nanoscale technologies and science applied to the life sciences. The facilities of this center are distributed between Clark Hall and Duffield Hall.

*National Astronomy and Ionosphere Center.* NAIC is the world's largest radio-radar telescope facility, operated by Cornell in Arecibo, Puerto Rico, focusing on radio and radar astronomical studies and investigations of the Earth's ionosphere.

*National Institutes of Health/National Science Foundation Developmental Resource in Biophysical Imaging and Optoelectronics.* This resource develops novel measurement and optical instrumentation for solving biophysical problems.

*National Nanotechnology Infrastructure Network.* NINN, a partnership of 13 university-based labs, provides access to infrastructure to enable the national science and engineering community to pursue research, education, and technology development dealing with nanotechnology.

*National Science Digital Library.* The NSDL project at Cornell, part of the NSF's national effort in developing resources and tools for digital libraries, hosts the production services for NSF's NSDL and designs and implements technical infrastructure.

*Network for Earthquake Engineering Simulation (NEES).* A system of nationwide experimental facilities linked by high-performance Internet for laboratory and computational simulation of structures under earthquake loads.

*Northeast Regional Climate Center.* This center monitors and reports on current climate conditions in the region.

*Northeast Sun Grant Institute of Excellence.* Partners in this initiative are involved in addressing energy needs and revitalizing rural communities with land-grant university research, education, and extension programs.

*Power Systems Engineering Research Center.* A National Science Foundation cooperative center between university and industry centered on power systems and infrastructure networks research.

*Program of Computer Graphics.* This interdisciplinary research center operates one of the most advanced computer-graphics laboratories in the United States.

*Program on Science, Technology, and Society.* This cross-disciplinary unit sponsors courses and promotes research on the interaction of science, technology, and society.

*Transportation Infrastructure Research Consortium.* Cornell is the lead institution in this consortium of 12 institutions in New York State. It brings together the research expertise in a cross-disciplinary fashion to solve problems in cooperation with the staff of the New York State Department of Transportation, its principal sponsor.

*W. M. Keck Foundation in Nanobiotechnology.* Facilities of this program include tools for nanoscale diagnostics of biomaterials.

The programs listed above are sponsored by College of Engineering units, and several are industry affiliated.

## DEGREE PROGRAMS

Cornell programs in engineering and applied science lead to the degrees of bachelor of science (B.S.), master of engineering (with field designation) (M.Eng.), master of science (M.S.), and doctor of philosophy (Ph.D.).

General academic information concerning the B.S. degree is given below under "Undergraduate Study." The student pursues the degree in one of 13 majors. The majors are described under "Engineering Majors."

Many students stay a fifth year in the College of Engineering to pursue a professional degree, the master of engineering (M.Eng.) degree. Joint enrollment in the B.S. and M. Eng. degrees is possible for students in their last semester who lack only 1 to 8 credits for the B.S.

M.Eng. degrees are awarded in most of the major areas. In addition, the following M.Eng. degrees are awarded: aerospace engineering, biomedical engineering, electrical engineering, engineering mechanics, nuclear engineering, operations research and industrial engineering, and systems engineering. For full details on M.Eng. degrees, see "Master of Engineering Degree Programs."

Programs leading to the M.S. and Ph.D. degrees are administered by the Graduate School. They are described in the *Announcement of the Graduate School* and the special announcement *Graduate Study in Engineering and Applied Science.*

## UNDERGRADUATE STUDY

Students in the College of Engineering spend most of their first two years of undergraduate studies in the Common Curriculum, which is administered by the College Curriculum Governing Board (CCGB) through the associate dean for undergraduate programs and Engineering Advising. At the end of their third semester, they affiliate with one of these majors:*

biological engineering (BE)†

chemical engineering (ChemE)

civil engineering (CE)

computer science (CS)

electrical and computer engineering (ECE)

engineering physics (EP)

environmental engineering (EnvE)

independent major (IM)

information science, systems, and technology (ISST)—with options in information science and management science

materials science and engineering (MSE)

mechanical engineering (ME)

operations research and engineering (ORE)

science of earth systems (SES)

Criteria for affiliation with the majors are described under "Affiliation with a Major." The majors are described under "Undergraduate Engineering Majors."

Most of the majors have a corresponding minor, in which the student can pursue a secondary interest. In addition, there are minors in applied mathematics, biomedical engineering, civil infrastructure, engineering management, engineering statistics, game design, industrial systems and information technology, information science, and business. See the main section, "Engineering Minors."

*The majors biological engineering, chemical engineering, civil engineering, electrical and computer engineering, materials science and engineering, and mechanical engineering are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

†Students may major in biological engineering through the College of Engineering or the College of Agriculture and Life Sciences (CALS). Students who do so through the College of Agriculture and Life Sciences are jointly enrolled with the College of Engineering for their last two years.

There is no undergraduate major in nuclear science and engineering. Students who intend to enter graduate programs in this area are encouraged to begin specialization at the undergraduate level. This may be done by choice of electives within the major (e.g., engineering physics, materials science and engineering, civil engineering, chemical engineering, and the independent major). Contact a faculty member in the graduate field of nuclear science and engineering who is most directly concerned with the curriculum, including K. B. Cady, D. A. Hammer, R. W. Kay, and V. O. Kostroun.

### Graduation Requirements

To receive the bachelor of science degree, students must meet the requirements of the common curriculum (outlined below) as set forth by the College of Engineering, including the requirements of their chosen major, as established by the school or department that administers the major. (Further explanation of the revised common curriculum and major flow charts are provided in the 2008–2009 edition of the *Engineering Undergraduate Handbook.*)

| *Course Category* | *Credits* |
|---|---|
| 1. Mathematics (major-specific) | 15–16 |
| 2. Physics (major-specific) | 8–12 |
| 3. Chemistry (major-specific) | 4–8 |
| 4. First-year writing seminar | 6 |
| 5. Technical writing* | 3 |
| 6. Computing | 5 |
| 7. Introduction to engineering (ENGRI) | 3 |
| 8. Two engineering distributions (ENGRD) | 6–8 |
| 9. Liberal studies distribution (6 courses min.) | ≥ 18 |
| 10. Advisor-approved electives | 6 |
| 11. Major program | |
| a. Major-required courses | ≥ 30 |
| b. Major-approved electives | 9 |
| c. Courses outside the major | 9 |
| 12. Two semesters of physical education in the freshman year and demonstration of proficiency in swimming (university requirement) | |

From 124 to 134 credits are required for graduation, depending on the major (see "Engineering Majors").

*Technical-writing courses may simultaneously fulfill another requirement.

#### Mathematics

The normal program in mathematics includes MATH 1910, 1920, 2930 or 2940 (depending on the major), and a major-specific math course. At least C– must be attained in these courses; if not, the course must be repeated immediately before the next course in the sequence is taken. Failure to achieve at least C– the second time will result in withdrawal from the College of Engineering. Courses that are taken a second time do not yield additional credit toward a degree.

#### Physics

The normal program in physics includes PHYS 1112, 2213, and 2214 or the corresponding honors courses (PHYS 1116, 2217, and 2218). Engineering students must attain at least C– in each math prerequisite of a physics course before taking the physics course (e.g., C– in MATH 1910 before taking PHYS 1112 and C– in MATH 1920 before taking PHYS 2213). The following substitutions are allowed for PHYS 2214: ChemE, CE, CS, ISST, and SES majors: CHEM 2080. BE and EnvE majors: CHEM 1570 or 3570. ORE majors: CHEM 2080, CS 2800, or MATH 3040, 3110, or 3360.

#### Chemistry

CHEM 2090 is required. The content is the same as that of CHEM 2070, but Engineering students are expected to take 2090.

Typically, CHEM 2090 is taken during the freshman year, but students who wish to complete the physics program (PHYS 1112, 2213, and 2214) first may postpone CHEM 2090 until the sophomore year.

Students considering chemical engineering must take CHEM 2090 in the fall of their freshman year and CHEM 2080 in the spring semester. Students considering the Science of Earth Systems major or a health-related career such as medicine should take the CHEM 2090–2080 sequence.

#### Computing

Students learn about computing using two programming languages by taking one of two sequences: (1) CS 1110 and CS 1132 or (2) CS 1112 (BE majors may take BEE 1510 instead) and CS 1130. The first course is taken in the first year. The second course, a 1-credit S–U course, is taken as soon as possible thereafter but no later than the fourth semester.

#### First-Year Writing Seminars

Each semester of their freshman year, students choose a first-year writing seminar from over 100 courses offered by over 30 different departments in the humanities, social sciences, and expressive arts. These courses offer the student practice in writing English prose. They also ensure beginning students the benefits of a small class.

#### Technical Writing

Students can fulfill the upper-level technical-writing requirement using one of the six alternatives below. See www.engineering.cornell.edu/ECP/ for more information.

1. ENGRC 3500 or 3350
2. The Writing-Intensive Co-op—an opportunity to combine work and academics. Some co-op students do a significant amount of writing on the job; under certain circumstances, this writing

will satisfy the technical-writing requirement.

3. An officially designated Writing-Intensive (W-I) engineering course:
   - ENGRD/AEP 2640
   - CHEME 4320
   - MSE 4030 and 4040 (both)
   - MSE 4050 and 4060 (both)
   - MAE 4272
   - BEE 4530
   - BEE 4730 with co-registration in BEE 4930
   - BEE 4890
4. ENGRC 3020, a 1-credit attachment to an engineering course that is not one of the officially designated W-I courses (see #3 above). An instructor may wish to extend the writing in their course for a given semester so that it will fulfill the technical-writing requirement. With the approval of the CCGB's Subcommittee on Technical Writing, the instructor may have students co-register in ENGRC 302, which may be taken more than once with different courses by permission of the engineering instructor.
5. COMM 2600, 2630, or 3520, taught by the Department of Communication (in the College of Agriculture and Life Sciences).
6. Petition. Occasionally, a student will be doing a significant amount and variety of technical writing elsewhere in the College of Engineering. It may be appropriate to petition the CCGB's Subcommittee on Technical Writing for permission to use this forthcoming writing (not past writing) to meet the technical-writing requirement.

### Introduction-to-Engineering Course

An introduction-to-engineering course (designated ENGRI) must be taken during the freshman year. This course introduces students to the engineering process and provides a substantive experience in an open-ended problem-solving context. See the Introduction-to-Engineering course listing for current course offerings.

### Engineering Distribution

Two engineering distribution (ENGRD) courses (6–8 credits) must be selected from two different categories listed below. A student may use any one of the possible substitutions described.

1. *Scientific computing*

   ENGRD 2110 Object Oriented Programming and Data Structures

   ENGRD 3200 Engineering Computation

   ENGRD 3510 Numerical Methods in Computational Molecular Biology

   ENGRD 3220 Introduction to Scientific Computation
2. *Materials science*

   ENGRD 2610 Introduction to Mechanical Properties of Materials: From Nanodevices to Superstructures

   ENGRD 2620 Electronic Materials for the Information Age
3. *Mechanics*

   ENGRD 2020 Mechanics of Solids

   ENGRD 2030 Dynamics

   Majors in Engineering Physics may substitute AEP 3330 for ENGRD 2030.
4. *Probability and statistics*

   ENGRD 2700 Basic Engineering Probability and Statistics

   Majors in Electrical and Computer Engineering may substitute ECE 3100 for ENGRD 2700. Majors in Engineering Physics may substitute ECE 3100 or MATH 4710 for ENGRD 2700. Majors in Civil Engineering, Biological Engineering, and Environmental Engineering may substitute CEE 3040 for ENGRD 2700.
5. *Electrical sciences*

   ENGRD 2100 Introduction to Circuits for Electrical and Computer Engineers

   ENGRD 2300 Introduction to Digital Logic Design

   ENGRD 2640 Computer-Instrumentation Design
6. *Thermodynamics and energy balances*

   ENGRD 2190 Mass and Energy Balances

   ENGRD 2210 Thermodynamics
7. *Earth and life sciences*

   ENGRD 2010 Introduction to the Physics and Chemistry of the Earth

   ENGRD 2510 Engineering for a Sustainable Society

   ENGRD 2600 Principles of Biological Engineering
8. *Biology and chemistry*

   ENGRD 2520/AEP 2520 The Physics of Life

   BIOG 1101 and 1103 Biological Sciences, Lec and Lab

   BIOG 1105 Introductory Biology

   BIOG 1107 General Biology (summer only)

   CHEM 3890 Physical Chemistry I

Some majors require a specific engineering distribution course as a prerequisite for the upper-class course sequence. These requirements are as follows:

Biological Engineering: ENGRD 2020

Chemical Engineering: ENGRD 2190

Civil Engineering: ENGRD 2020

Computer Science: ENGRD 2110 (co-enrollment in CS 2111 highly recommended)

Electrical and Computer Engineering: ENGRD 2300

Environmental Engineering: ENGRD 2020

Geological Sciences: ENGRD 2010

Information Science, Systems, and Technology: ENGRD 2700

Materials Science and Engineering: ENGRD 2610 or ENGRD 2620

Mechanical Engineering: ENGRD 2020

Operations Research and Engineering: ENGRD 2700

Some majors require additional distribution courses after affiliation.

### Liberal Studies Distribution

Global and diverse societies require that engineers have an awareness of historical patterns, an appreciation for different cultures, professional ethics, the ability to work in multifaceted groups, and superior communications skills. Cornell has a rich curriculum in the humanities, arts, and social sciences, enabling every engineering student to obtain a truly liberal education. At least six courses (totaling at least 18 credits) are required, and they should be chosen with as much care and foresight as courses from technical areas.

- The six courses must be chosen from at least three of the following six groups.
- At least two of the six courses must be at the 2000 level or higher.

Utilize the current *Courses of Study* as the master list of approved Liberal Studies courses. Additional approved courses and unacceptable courses can be viewed at www.engineering.cornell.edu/student-services/academic-advising/index.cfm. Lists of additional approved courses and unacceptable courses are also available in Engineering Advising, 167 Olin Hall.

**Group 1. Cultural Analysis (CA)**
Courses in this area study human life in particular cultural contexts through interpretive analysis of individual behavior, discourse, and social practice. Topics include belief systems (science, medicine, religion), expressive arts and symbolic behavior (visual arts, performance, poetry, myth, narrative, ritual), identity (nationality, race, ethnicity, gender, sexuality), social groups and institutions (family, market, community), and power and politics (states, colonialism, inequality).

**Group 2. Historical Analysis (HA)**
Courses in this group interpret continuities and changes—political, social, economic, diplomatic, religious, intellectual, artistic, and scientific—through time. The focus may be on groups of people, dominant or subaltern, a specific country or region, an event, a process, or a time period.

**Group 3. Literature and the Arts (LA)**
Offerings in this area explore literature and the arts in two different but related ways. Some courses focus on the critical study of artworks and on their history, aesthetics, and theory. These courses develop skills of reading, observing, and hearing and encourage reflection on such experiences; many investigate the interplay among individual achievement, artistic tradition, and historical context. Other courses are devoted to the production and performance of artworks (in creative writing, performing arts, and media such as film and video). These courses emphasize the interaction among technical mastery, cognitive knowledge, and creative imagination.

**Group 4. Knowledge, Cognition, and Moral Reasoning (KCM)**
Offerings in this area investigate the bases of human knowledge in its broadest sense, ranging from cognitive faculties shared by humans and animals such as perception, to abstract reasoning, to the ability to form and justify moral judgments. Courses investigating the sources, structure, and limits of cognition may use the methodologies of science, cognitive psychology, linguistics, or philosophy. Courses focusing on moral reasoning explore ways of reflecting on ethical

questions that concern the nature of justice, the good life, or human values in general.

**Group 5. Social and Behavioral Analysis (SBA)**
Courses in this area examine human life in its social context through the use of social-scientific methods, often including hypothesis testing, scientific sampling techniques, and statistical analysis. Topics studied range from the thoughts, feelings, beliefs, and attitudes of individuals to interpersonal relations between individuals (e.g., in friendship, love, conflict) to larger social organizations (e.g., the family, society, religious or educational or civic institutions, the economy, government) to the relationships and conflicts among groups or individuals (e.g., discrimination, inequality, prejudice, stigmas, conflict resolution).

**Group 6. Foreign Languages (not literature courses)**
Courses in this area teach language skills, inclusive of reading, writing, listening, and spoken non-English languages, at beginning to advanced levels.

### Electives

- **Advisor-approved electives:** 6 credits required (approved by the academic advisor). Because these courses should help develop and broaden the skills of the engineer, advisors generally accept the following as approved electives:

1. One introduction-to-engineering course (ENGRI)
2. Engineering distribution courses
3. Courses stressing written or oral communication
4. Upper-level engineering courses
5. Advanced courses in mathematics
6. Rigorous courses in the biological and physical sciences
7. Courses in business, economics, or language (when they serve the student's educational and academic objectives)
8. Courses that expand the major or another part of the curriculum.
9. Up to 6 credits of advisor-approved electives may come from ROTC courses at the 300 level or higher.

- **Major-approved electives:** 9 credits (approved by the major and faculty advisors in the major). Refer to the major curricula for descriptions of courses in this category.
- **Outside-the-major electives:** 9 credits of courses outside the major to ensure breadth of engineering studies

### Social Issues of Technology

It is important for engineers to realize the social and ethical implications of their work. Consequently, in selecting their liberal studies distribution courses and approved electives, students are urged to consider courses listed in the "Science and Technology Studies" undergraduate area of concentration (see "Interdisciplinary Centers and Programs"). These courses may provide students with important perspectives on their studies and their future careers.

## Engineering Advising

Entering first-year students are assigned a faculty advisor (who may or may not be in their intended major), who remains their advisor until affiliation with a major (normally during the fourth semester). The students are also under the administration of Engineering Advising in 167 Olin Hall, which implements the academic policies of the College Curriculum Governing Board. Engineering Advising serves as the primary resource center for undergraduate students in the college, offering general advising and academic counseling. Other student services offices located in Olin Hall are Engineering Learning Initiatives and Diversity Programs in Engineering (DPE), which are primary resources for academic counseling, support, tutoring, and networking opportunities.

## First-Year Requirements

During the first year, engineering students are expected to complete (or receive credit for) the following core requirements:

- MATH 1910 and 1920
- Two of: CHEM 2090, 2080, PHYS 1112, 2213, 2214* (or the Honors equivalent)
- One of: CS 111X
- Two first-year writing seminars
- One introduction to engineering (ENGRI) course
- Two physical education courses

*Students with an interest in pre-med (or other health-related careers), chemical engineering, or Science of Earth Systems should enroll in the CHEM 2090–2080 sequence during their first year.

## Affiliation with a Major

Students must apply for affiliation with a major during the first semester of their sophomore year, although earlier affiliation may be granted at the discretion of the major. This is done by visiting the undergraduate major office and completing the application for major affiliation form. To affiliate, students must (1) make good progress toward completing required courses in the common curriculum, (2) have a GPA ≥ 2.0, and (3) have satisfied the major's course and grade requirements as specified below:

(Majors may impose alternative affiliation requirements for students applying for affiliation later than the first semester of the sophomore year.)

| *Major* | *Courses and Minimum Grade Requirements* |
|---|---|
| Biological Engineering | GPA ≥ 2.5 and at most one grade below C– in math, science, and engineering courses. Completion of ENGRD 2600 (or 2510) and Intro Biology Sequence by end of the sophomore year with grade of at least C– in all courses. (Also applies to transfer students). |
| Chemical Engineering | At most one grade below C– in chemistry, math, physics, and chemical engineering courses. GPA ≥ 2.2 in math, science, and engineering courses. |
| Civil Engineering | GPA ≥ 2.0 in all engineering and science courses. At least C– in ENGRD 2020 (or ENGRD 2510, for students who do not take ENGRD 2020 before affiliation). |
| Computer Science | At least C in all completed CS and math courses. GPA ≥ 2.5 in CS 2110, 2111, and 2800. GPA ≥ 2.5 in MATH 1920 and CS 2800. Visit the CS undergraduate office web site for alternative affiliation criteria. |
| Electrical and Computer Engineering | At least C+ in MATH 2930, PHYS 2213, and one of ECE/ENGRD 2100, ECE 2200, or ECE/ENGRD 2300. GPA ≥ 2.5 in (if completed): MATH 1920, 2930, 2940, PHYS 2213, ENGRD 2110, ECE/ ENGRD 2300, ECE/ ENGRD 2100, ECE 2200. |
| Engineering Physics | At least B– in all required math and physics courses. |
| Environmental Engineering | GPA ≥ 2.0 in all engineering and science courses. At least C– in ENGRD 2510. |
| Independent Major | GPA ≥ 2.0. |
| Information Science Systems, and Technology | At least C in two of MATH 2940, CS 2110, and ORIE/ENGRD 2700. Courses must be taken for a letter grade. GPA ≥ 2.3 in completed engineering math, engineering distribution, and ISST major courses, which must be taken at Cornell. For a repeated course, the most recent grade will be used. |
| Materials Science and Engineering | At least C– in required physics, chemistry, and math courses. At least C in ENGRD 2610 or ENGRD 2620. |
| Mechanical Engineering | At least C– in ENGRD 2020, ENGRD 2210*, and all completed required math, science, and computer science courses. GPA ≥ 2.5 in MATH 2930, PHYS 2213, ENGRD 2020, and ENGRD 2210 (if ENGRD 2210 was taken). For students entering prior to fall 2005, see affiliation requirements at www.mae.cornell.edu. |
| Operations Research and Engineering | At least C in each of ENGRD 2700 and MATH 2940. GPA ≥ 2.0 in math, science, and engineering courses (both overall and in the term immediately before affiliation). At least C– in all ORIE courses completed thus far. Good academic standing in the College of Engineering. |

| | |
|---|---|
| Science of Earth Systems | Good academic standing in the College of Engineering. |

Students must be affiliated or conditionally affiliated with a major by the end of their fourth semester or they will be withdrawn from the College of Engineering, unless allowed to participate in a terminal semester.

# SPECIAL PROGRAMS

## Dual-Degree Program

The dual-degree program, intended for superior students, allows both a bachelor of science and either a bachelor of arts (B.A.) or bachelor of fine arts (B.F.A.) degree to be earned in about five years. Students registered in the College of Engineering, the College of Arts and Sciences, or the College of Architecture, Art, and Planning may apply and, after acceptance of their application, begin the dual-degree program in their second or third year. For information, contact the appropriate coordinators of dual-degree programs at 55 Goldwin Smith Hall (for Arts and Sciences), B-1 West Sibley Hall (for Architecture, Art, and Planning), and Engineering Advising, 167 Olin Hall.

## Double Major in Engineering

The double-major option, which makes it possible to develop expertise in two allied engineering majors, generally requires at least one semester beyond the usual four years. Students affiliate with one major following normal procedures and then petition to enter a second major before the end of their junior year. All requirements of both majors must be satisfied. Further information is available from Engineering Advising, 167 Olin Hall, and the individual major offices.

## Independent Major

Students whose educational objectives cannot be met by one of the regular majors may affiliate with the independent major. Often, the desired curriculum is in an interdisciplinary area.

This major consists of a primary area (≥ 32 credits), which may be any subject area offered by a school or department of the college, and an educationally related secondary area (≥ 16 credits), which may be in a second engineering subject area or in a logically connected nonengineering area. The combination must form an engineering education in scope and substance and should include engineering design and synthesis as well as engineering sciences. See the discussion of this major in “Undergraduate Engineering Majors.”

## Engineering Minors

Students may pursue minors in any department in any college that offers them, subject to limitations placed by the department offering the minor or by the students’ major. Completed minors will appear on the student’s transcript. Not all departments offer minors. Consult the appropriate section in *Courses of Study* or contact the appropriate department for information on minors offered and how to pursue a minor.

Most engineering majors have a corresponding minor, requiring six courses (18 credits), in which the student can pursue a secondary interest. In addition, there are minors in applied mathematics, biomedical engineering, civil infrastructure, engineering management, engineering statistics, game design, industrial systems and information technology, information science, and business. See “Engineering Minors.”

## Engineering Communications Program

424 Hollister Hall, 255-8558, www.engineering.cornell.edu/ECP

The Engineering Communications Program (ECP), provides instruction in technical writing, oral presentation, and the use of graphics in both. The ECP is a recipient of the Engineering Dean’s Prize in Excellence and Innovation in Teaching.

ECP courses give students experience with the difficult task of explaining technical information to audiences that have various levels of technical expertise. Students improve their writing style, become more comfortable with and effective at oral presentation, use standard forms and formats for presenting technical information, perform library and Internet research on engineering topics, and study real engineering situations in which ethics may have been breached.

Enrollment in ECP courses is typically 20 students per section; like writing seminars elsewhere at Cornell, those taught by the ECP are discussion classes. Students’ work receives abundant written comments, and conferences are frequent.

ECP members are available to consult with the faculty teaching writing-intensive technical courses and anyone else interested in including writing in their courses. They oversee the communications component of the Writing-Intensive Co-op and occasionally give talks to alumni and student groups.

## Diversity Programs in Engineering

146 Olin Hall, 255-6403

The Diversity Programs in Engineering (DPE) office operates programs at the undergraduate, graduate, and faculty levels to facilitate the outreach, recruitment, retention, and overall success of underrepresented minorities, women, and other underrepresented groups in Engineering. DPE serves as a resource center for academic support, career placement, graduate school preparation, and overall student success.

The office participates in a university-wide pre-freshman summer program (Engineering Summer Scholars Program) for admitted students, coordinates two summer program initiatives for high school students, CURIE (www.engineering.cornell.edu/curie) and CATALYST (www.engineering.cornell.edu/catalyst), and also provides specialized instruction, in collaboration with Engineering Advising and Engineering Learning Initiatives, each semester in subjects such as math, computer science, and English composition.

The DPE office sponsors networking events throughout the academic year that allow company representatives from all over the United States to meet students from diverse populations. Summer internships and permanent jobs frequently result from these events.

In addition, the DPE office coordinates various trips, recreational activities, seminars, lectures, and workshops on a wide range of topics that are relevant to academic and extracurricular life in the university setting.

## Engineering Learning Initiatives

167 Olin Hall, 255-9622, www.engineering.cornell.edu/learning

The office of Engineering Learning Initiatives offers programs designed to enhance the undergraduate academic experience through peer education, cooperative learning, research opportunities, and leadership development.

*Academic Excellence Workshops* (AEWs) offered through Engineering Learning Initiatives are taken in conjunction with core engineering courses in math, computer science, and chemistry. The 1-credit AEWs are weekly two-hour cooperative learning sessions. Designed to enhance student understanding, they feature peer-facilitated group work on problems at or above the level of course material.

*Undergraduate Research Grants* offered through Engineering Learning Initiatives provide opportunities for students to obtain hands-on research experience with a faculty mentor. Students and faculty may apply for funding to cover student stipend and expense costs for the fall, spring, and summer terms.

*Tutors-on-Call,* through Engineering Learning Initiatives, offers one-on-one peer tutoring free of charge for engineering students in many first- and second-year core courses, including math, chemistry, physics, computer science, and distribution courses.

*LeaderShape*, offered through Engineering Learning Initiatives, provides opportunities for our students to engage in the dynamic process of personal discovery and leadership development at a week-long retreat held in May of each year.

## Engineering Cooperative Education and Career Services

201 Carpenter Hall, 255-5006, www.engineering.cornell.edu/careerservices

This office assists engineering students (freshmen through Ph.D.) on issues related to career development and the job search through individual advising and group seminars. It also administers the Engineering Cooperative Education Program. Each year, more than 200 national employers visit the office to recruit technical interns and graduates; additional job opportunities are posted on Cornell’s electronic job posting service. Both undergraduate and graduate students can use these resources to pursue permanent, summer, or co-op employment; however, students seeking co-op opportunities must meet specific requirements.

The Engineering Cooperative Education Program (Co-op) provides an opportunity for students to gain practical experience in engineering-related organizations before they graduate. By supplementing course work with carefully monitored, paid positions, Co-op students can explore their own interests and acquire a better understanding of engineering as a profession—and still graduate in four years.

To be eligible, a student must have been enrolled in the College of Engineering an equivalent of five semesters before starting the first work term. (Exceptions may be made for transfer students and others pursuing an accelerated curriculum.) Students majoring in computer science or biological engineering, but not registered in the College of Engineering, are also eligible. In most cases, a GPA ≥ 2.7 is required. Applicants interview with participating employers in February of the sophomore year. Those who receive offers and join the program usually complete their fifth-semester course work on campus during the summer after sophomore year and begin the first Co-op work term the following fall. They complete the sixth semester on campus with their classmates and then return to their Co-op employer (but not necessarily to the same department or location) the following summer to complete a second work term. Students then spend the senior year on campus, graduating on schedule with their class. Students who have flexible course curriculums may prefer to complete one 28-week spring/summer or summer/fall Co-op work term during the junior year.

### International Programs

An international perspective, sensitivity to other cultures, and the ability to read and speak a second language are increasingly important for today's engineers. The College of Engineering encourages students to study or work abroad during their undergraduate years. Currently, the college has study abroad agreements with École Centrale Paris, France; Cantabria, Spain; and the Hong Kong University of Science and Technology and is also working with IIT Kanpur, India, and the National University of Singapore. The college is working to facilitate study abroad in Dresden, Germany; and Guadalajara, Mexico. Students who plan to study abroad apply through Cornell Abroad; see the Cornell Abroad program description in the introductory section of *Courses of Study*. Visit www.engineering.cornell.edu/studyabroad and Engineering Advising, 167 Olin Hall, for the latest information. In addition, the college is working on developing international Co-op and internship work experiences. For information, visit the Engineering Cooperative Education and Career Services Office, 201 Carpenter Hall.

### Cooperative Program with the Johnson Graduate School of Management

Undergraduates may be interested in a cooperative program at Cornell that leads to both master of engineering and master of business administration (M.B.A.) degrees. See "Master of Engineering Degrees" for details.

### Lester Knight Scholarship Program

The Lester Knight Scholarship Program is designed to assist and encourage Cornell Engineering students and alumni interested in combining their engineering education with a business degree. See "Master of Engineering Degrees" for details.

## ACADEMIC PROCEDURES AND POLICIES

### Advanced Placement Credit

The College of Engineering awards a significant amount of advanced placement (AP) credit to entering first-year students who demonstrate proficiency in the subject areas of introductory courses. Students can earn AP credit by receiving qualifying scores on any of the following:

1. Advanced placement examinations given and scored by the College Entrance Examination Board (CEEB);
2. General Certificate of Education (GCE) Advanced ("A") Level Examinations;
3. International Baccalaureate (IB) Higher Level Examinations; or
4. Cornell's departmental placement examinations, given during orientation week before the beginning of fall-semester classes.

Advanced placement credit is intended to permit students to develop more challenging and stimulating programs of study. Students who receive AP credit for an introductory course may use it in three different ways. They may:

1. enroll in a more advanced course in the same subject right away.
2. substitute an elective course from a different area.
3. enroll in fewer courses, using the AP credit to fulfill basic requirements.

### Acceptable Subjects and Scores for CEEB or Cornell Departmental AP Exams

The most common subjects for which AP credit is awarded in the College of Engineering, and the scores needed on qualifying tests, are listed below. AP credit is awarded only for courses that meet engineering curriculum requirements.

**Mathematics:** MATH 1910, 1920 are required.

*First-semester math* (*MATH 1910*). AP credit may be earned by:

- a score of 4 or 5 on the CEEB BC exam, or
- a passing score on the Cornell departmental exam for first-semester math.

*First-year math (through MATH 1920).* AP credit may be earned by:

- a passing score on the Cornell departmental exam for first-year math.

**Physics:** PHYS 1112 and 2213 are required.

*PHYS 1112.* AP credit may be earned by:

- a score of 4 or 5 on the mechanics portion of the CEEB C exam, or
- a score of 5 on the CEEB B exam with successful completion of a high school–level calculus course, *or*
- a passing score on the Cornell departmental exam for PHYS 1112.

**Note:** MATH 2930 is a prerequisite for PHYS 2214.

*PHYS 2213.* AP credit may be earned by a score of 5 on the Electricity and Magnetism portion of the AP C exam.

*PHYS 1116, 2217, and 2218* (honors sequence). This sequence is designed for students with strong experience in physics and calculus,
e.g., a 5 on one or both Physics C AP tests and the equivalent of at least one semester of university calculus. Students interested in PHYS 2217 or 2218 are strongly advised to start with PHYS 1116. Even for a student with a 5 on both Physics C AP tests, 1116 will not be boring. Students may not simultaneously receive credit for PHYS 1116 and AP credit for PHYS 1112, or credit for PHYS 2217 and AP credit for PHYS 2213. For advice or more information, contact the departmental representative at 255-6016.

**Chemistry:** CHEM 2090 is required.

*CHEM 2090.* AP credits may be earned by:

- a score of 5 on the CEEB AP exam, or
- a passing score on the Cornell departmental exam for chemistry.

**Note:** Students who obtain AP credit for CHEM 2090 and who are considering a major in chemical engineering or materials science and engineering should consider enrolling in CHEM 2150. Those who are offered AP credit for CHEM 2090 and then elect to take CHEM 2150 will also receive academic credit for CHEM 2090. Students may want to discuss this option with their faculty advisor.

**Computing:** CS 1110 or CS 1113 or CS 1112 or CS 1114, together with CS 1132 or CS 1130, are required. AP credit may be earned for CS 1110 by:

- a score of 5 on the CEEB A or a score of 4 or 5 on the AB exam, or
- a passing score on the Cornell departmental exam for CS 1110.

**Biology:** Biology is not required as part of the core curriculum, although it is a popular elective, especially for students who intend to pursue health-related careers. AP credit may be earned as follows:

- 8 credits will be offered to students who receive a 5 on the CEEB AP exam;
- 4 credits will be offered to students who receive a 4 on the CEEB AP.

Those who want to study more biology should contact the Office of Undergraduate Biology, 200 Stimson Hall, to discuss proper placement.

**First-year writing seminar:** Two first-year writing seminars are required.

- AP credit for one first-year writing seminar may be earned by a score of 5 on either of the CEEB AP English exams.

Students who earn a score of 4 on the AP English Literature and Composition exam or the AP English Language and Composition exam will be offered 3 credits, which may be applied toward the Literature and Arts (LA) category of the Liberal Studies distribution requirement.

**Liberal studies distribution:** Six courses beyond two first-year writing seminars are required. Students may earn AP credit toward the liberal studies distribution by taking College Entrance Examination Board (CEEB) AP tests. AP credit earned in the liberal studies distribution cannot be used to fulfill the "upper-level" liberal studies requirements.

**Languages:** Students may earn AP credit for competence in a foreign language by taking the College Entrance Examination Board (CEEB) AP test or by taking the Cornell Advanced Standing Examination (CASE). Those who score 4 or 5 on the CEEB AP test in French, German, Italian, and Spanish are entitled to 3 credits. To qualify for the CASE exam (in any language), the student must score at least 65 on a college placement test (taken either in high school or at Cornell during Orientation Week). A passing score on the CASE entitles the student to 3 credits. Language credit, earned via AP or CASE, may be used to satisfy part of the foreign language category of the liberal studies distribution or may meet an approved elective requirement, contingent on discussions with the faculty advisor.

## Advanced Placement and Credit for International Credentials

Students who have successfully completed either a General Certificate of Education (GCE) Advanced ("A") Level Examination or an International Baccalaureate (IB) Higher Level Examination may be eligible for advanced placement credit in the College of Engineering as follows:

**General Certificate of Education Advanced Level Examination (GCE "A")**

Hong Kong Advanced Level examinations and the joint examination for the Higher School Certificate and Advanced Level Certificate of Education in Malaysia and Singapore—principal passes only—are considered equivalent in standard to GCE "A" Levels.

| *Subject* | *Marks* | *Credit* |
|---|---|---|
| Biology | A or B | 8 credits |
| Chemistry | A | 8 credits (CHEM 2090 and 2080) |
| | B | 4 credits (CHEM 2090) |
| Mathematics or Pure Mathematics | A, B, or C | 4 credits (MATH 1910) |
| Physics | A or B | 4 credits for PHYS 1112; 4 additional credits for PHYS 2213 are granted to a combination of grades of A or B and a minimum of 4 Advanced Placement (or advanced standing) credits in mathematics. |

**International Baccalaureate (IB) Higher Level Examination**

| *Subject* | *Marks* | *Credit* |
|---|---|---|
| Biology | 7 | 8 credits |
| | 6 | 6 credits |
| Chemistry | 6 or 7 | 4 credits (CHEM 2090) |
| Computer Science | 6 or 7 | 4 credits (CS 1110 |
| Physics | 6 or 7 | 4 credits (PHYS 1112) |

Mathematics: No credit is given for the IB exam; students are encouraged to take the Engineering Mathematics Advanced Standing exam during orientation.

Note: Advanced placement credit based on GCE or IB results may also be awarded for courses that satisfy the liberal studies requirement in the College of Engineering. In such cases, the College of Engineering follows the AP guidelines found earlier in this publication under "General Information."

## General Policies for Advanced Placement

The general policies in the College of Engineering governing awards of AP credit are as follows:

1. AP credit will not be offered in any subject area without a documented examination.
2. All AP examinations are normally taken and scored before fall-semester classes begin. Students who take CEEB AP tests in high school should have an official report of their scores sent directly to Cornell as soon as possible. Students who have completed either GCE "A" Level or IB Higher Level Examinations must present the original or a certified copy of their examination certificate to Engineering Advising, 167 Olin Hall. Those who wish to take departmental examinations should do so during Orientation Week; permission to take these tests after the start of fall-semester classes must be requested in a written petition to the college's Committee on Academic Standards, Petitions, and Credit (ASPAC).

A more detailed description of the college's policies concerning advanced placement credit and its use in developing undergraduate programs may be found in the pamphlet *Advanced Placement and Transfer Credit for First-Year Engineering Students,* which may be obtained from Engineering Advising, 167 Olin Hall, and at www.engineering.cornell.edu/student-services/academic-advising/academic-information/ap-credit/index.cfm.

## General Policies for Transfer Credit

Undergraduate students who have completed courses at recognized and accredited colleges may, under certain conditions, have credits for such courses transferred to Cornell. Such courses must represent academic work in excess of that required for the secondary school diploma and must be documented as such in writing by the secondary institution. Courses deemed acceptable for transfer credit must be equivalent in scope and rigor to courses at Cornell. Transfer credit will not be awarded for courses taken during a semester in which the student is enrolled at Cornell.

- To apply for transfer credit, submit a transfer credit form (one form for each request), accompanied by a course description. (Forms are available from Engineering Advising or the Registrar's office and should be submitted before enrollment in the course to be transferred.) An official transcript from the offering institution (bearing the institutional seal and Registrar's signature) must be sent to the Engineering Registrar's office before official transfer credit will be awarded.
- Applications for transfer credit to satisfy requirements in math, science, engineering courses, or first-year writing seminars require approval from the department offering an equivalent course at Cornell. The department may require course materials, textbooks used, etc., in addition to the course description before approving the course.
- Departmental approval is not required for transfer credit that satisfies liberal studies distribution requirements. The course will be reviewed for approval by a representative of the Committee on Academic Standards, Petitions, and Credit (ASPAC) in Engineering Advising.
- Cornell does not award credit for courses in which a student has earned a grade less than C; schools and departments may stipulate a higher minimum grade.
- College courses completed under the auspices of cooperative college and high school programs will be considered for advanced placement credit only if students demonstrate academic proficiency by taking the appropriate AP or Cornell departmental placement examination (CASE), as described in the "Advanced Credit" section.
- Following matriculation, students may apply up to 18 credits of transfer and/or Cornell extramural credit toward B.S. degree requirements.
- At most 72 total transfer credits (taken both before and after matriculation) may be used to meet graduation requirements.
- Summer session courses taken at Cornell are not considered transfer credit.

A more detailed description of the college's regulations governing transfer credit may be found in the pamphlet *Advanced Placement and Transfer Credit for First-Year Engineering Students* as well as the *Engineering Undergraduate Handbook*, both available from Engineering Advising, 167 Olin Hall, and at www.engineering.cornell.edu/student-services/academic-advising/index.cfm.

## Transfer Credit for Transfer Students

Transfer students may transfer up to 36 credits for each year spent in full-time study at another institution, provided that the courses are acceptable for meeting graduation requirements. Transfer credit awards are determined by the majors/departments. Students must complete the transfer credit award process by the end of their first semester at Cornell, or their registration will be blocked for the next semester until the process is completed.

## Academic Standing

Full-time students are expected to remain in good academic standing. The criteria for good standing change somewhat as a student progresses through the four years of the engineering curriculum. At all times, the student must be making adequate progress toward a degree, but what this means depends on the major.

Engineering students not yet affiliated with a major must meet the following standards at the end of each semester to be considered in good academic standing. Failure to meet these standards will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC), and the actions of warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may be taken.

1. At least 12 credits passed, including *at least* two courses from math, science, and/or engineering (phys. ed. courses and courses below the 1000 level do not count)
2. At least C– in the math course
3. Semester GPA $\geq$ 2.0
4. No F, U, or INC grades

## Academic Progress

The total number of credits required for graduation range from 124 to 134, depending on the major. Therefore, an average semester credit load ranges from 15 to 17 credits.

Because math is pivotal to the study and practice of engineering, students must earn at least C– in their four required math courses. If at least C– is not attained, the course must be repeated immediately. Failure to achieve at least C– the second time will generally result in withdrawal from the College of Engineering. Physics and advanced math courses often have math prerequisites, and having to repeat the prerequisite course may delay progress in the physics and math curricula. Students are expected to continue the core engineering math courses each semester until completed.

## Dean's List

Dean's List citations are presented each semester to engineering students who have exemplary academic records. The dean of the college determines the criteria for this honor. For 2008–2009, the requirement is a semester GPA $\geq$ 3.4 (without rounding); no failing, unsatisfactory, missing, or incomplete grades (even in physical education); and at least 12 letter-grade credits (not S–U). Students may earn Dean's List status retroactively if they meet these criteria after making up incomplete grades. Students who earn Dean's List status receive certificates from the Engineering Registrar's office, and the honor is noted on the transcript.

## Graduating with Distinction and Honors

### Graduating with Distinction

Meritorious students graduating with a B.S. degree from the College of Engineering may also be designated *cum laude, magna cum laude,* or *summa cum laude*.

- Cum laude will be awarded to engineering students with a GPA $\geq$ 3.5. Cum laude will also be awarded to engineering students who received a semester GPA $\geq$ 3.5 in each of the last four semesters at Cornell; in each of these semesters, at least 12 letter-graded credits must be taken with no failing, unsatisfactory, missing, or incomplete grades. If the student is an engineering co-op student, then the engineering co-op summer term will count as one of the last four. Students who were approved for prorated tuition in their final semester will be awarded cum laude if they received a semester GPA $\geq$ 3.5 in their last semester and meet the conditions above in the prior four semesters.
- Magna cum laude will be awarded to engineering students with a GPA $\geq$ 3.75 (based on all credits taken at Cornell).
- Summa cum laude will be awarded to engineering students with a GPA $\geq$ 4.0 (based on all credits taken at Cornell).

*Note:* All GPA calculations are minimums and are not rounded.

### Major Honors Program

To be eligible to enter a major honors program, a student must be on track to graduate with distinction. A student must be in the program for at least two semesters before graduation. If the student's major has an approved honors program and the requirements for (1) distinction, (2) Bachelor of Science degree, and (3) major honors program are fulfilled, the faculty of the major may recommend that the student graduate with the additional diploma and transcript notation of "With Honors."

## S–U Grades

Many courses may be taken either for a letter grade or for an S–U (satisfactory or unsatisfactory) grade designation. Under the S–U option, students earning the letter grade equivalent of at least C– in a course will receive a grade of S; those earning less than C– receive U. A course in which a U grade is received does not count toward graduation requirements.

Engineering students may choose to receive an S–U grade option under the following conditions:

- The course in question must be offered with an S–U option.
- The student must previously have completed at least one full semester of study at Cornell.
- The proposed S–U course must count as either a liberal studies distribution or an advisor-approved elective in the engineering curriculum.
- Students may enroll S–U in only one course each semester in which the choice between letter grade and S–U is an option. (Additional courses offered "S–U grades only" may be taken in the same semester as the elected S–U course.)

The choice of grading option for any course is made initially during the pre-enrollment period and may be changed until the end of the third week of classes. After this deadline, the grading option may not be changed, nor will a student be permitted to add a course in which they were previously enrolled (in the current semester) under a different grade option. (Grading options may be changed online for most courses. A properly completed add/drop form must be used to change a grade option for a permission-only course.)

## Residence Requirements

Candidates for an undergraduate degree in engineering must spend at least four semesters or an equivalent period of instruction as full-time students at Cornell, including at least three semesters affiliated with an engineering major.

Students on a voluntary leave of absence may register for courses extramurally only with the approval of their major (or the college, for unaffiliated students). No more than 18 credits earned through extramural study or acquired as transfer credit (or a combination thereof) after matriculation may be used to satisfy the requirements for the B.S. degree in engineering. Students may not complete their last semester extramurally.

Degree candidates may spend periods of time studying away from the Cornell campus with appropriate authorization. Information on programs sponsored by other universities and on procedures for direct enrollment in foreign universities is available at the Cornell Abroad office, 474 Uris Hall. Programs should be planned in consultation with the staff of Engineering Advising, who can provide information on credit-evaluation policies and assist in the petitioning process.

## Transferring within Cornell

It is not uncommon for students to change their academic or career goals after matriculation in one college and decide that their needs would be better met in another college at Cornell. While transfer between colleges is not guaranteed, efforts are made to assist students in this situation.

The Internal Transfer Division office is responsible for assisting students with the transfer process. Students who wish to transfer out of the College of Engineering to another college at Cornell should consult initially with Engineering Advising.

Students who wish to transfer into the College of Engineering can apply at Engineering Advising, 167 Olin Hall. It is preferred that students apply in the semester in which they are completing affiliation criteria for the desired major. Transfer students who would enter the college must be accepted by a major as part of the admission process.

Students who wish to transfer into engineering should take courses in math, chemistry, computer science, physics, and engineering that conform to the requirements of the Common Curriculum. Students should discuss their eligibility with an advisor in Engineering Advising, 167 Olin Hall.

## Leave of Absence

A leave of absence may be voluntary, medical, or required. A description of each follows:

**Voluntary leave:** Students sometimes find it necessary to suspend their studies. To do this, they must petition for a leave of absence for a specified period of time and receive written approval.

Affiliated students request leave through their majors. Unaffiliated students request leave through Engineering Advising; the first step is an interview to establish conditions for the leave and subsequent return. Those who take a leave before affiliating with a major and while not in good standing may be given a "conditional leave." This requires them to meet specific conditions, established at the time the leave is granted, before they will be reinstated.

A leave of absence is granted for at least six months and not more than two years. A leave of absence granted during a semester goes into effect on the day it is requested. If a leave is requested after the 12th week of a semester, the courses in which the student was registered at the time of the request are treated as having been dropped (i.e., a "W" will appear on the transcript for each course). Students who owe money to the university are ineligible for a leave of absence. Courses taken during a leave to satisfy Cornell degree requirements must be approved *in advance* through a formal transfer petition. (See previous section, "Transfer Credit," for details.)

Students who intend to take a leave of absence should check with the Office of Financial Aid and Student Employment to discuss financial implications; this is especially true for those who have educational loans. Medical insurance eligibility may also be affected.

To return after a leave of absence, the conditions established when the leave was granted must be satisfied, and the college must be notified in writing at least six weeks before the beginning of the semester in which the student plans to return.

**Medical leave:** Medical leaves are granted by the college only upon recommendation by a physician or therapist from Gannett Health Center. Such leaves are granted for at least six months and up to two years with the understanding that the student may return at the beginning of any semester after the medical condition in question has been corrected. Students must satisfy the Gannett Health Center that the condition has been corrected before they may return. The student's academic standing will also be subject to review both at the time the leave is granted and upon the student's return.

**Required leave:** A required leave of absence is imposed in cases in which the academic progress of a student is so poor that continuing into the next semester does not appear prudent. An example of this might be failure in key engineering courses in a semester. Unless the student is ahead in the curriculum, returning later to repeat the semester makes better academic sense than continuing without the necessary background. In many cases, the leave is dictated by courses that are offered only in the fall or spring semester. Leaves are given when the probability of success is increased substantially by deferring the student's return by one semester (or, in unusual circumstances, one year).

### Rejoining the College

Students wishing to rejoin the college who have not yet affiliated with a major should request permission to rejoin in a letter to Engineering Advising; affiliated students should contact their major office. This must be done at least six weeks before the beginning of the semester in which the student wishes to return. The letter should describe the student's activities while away from Cornell, detail any academic work completed during this time, and specify the courses the student intends to take upon return.

### Withdrawal from the College

A withdrawal from the College of Engineering may be voluntary or required. Following is a description of each:

**Voluntary withdrawal:** Students who voluntarily withdraw from the college sever all connection with the college. Unaffiliated students who wish to withdraw should do so through Engineering Advising. Affiliated students should contact their major office. If a withdrawal is requested during the semester, courses in which the student is enrolled must be dropped in accordance with applicable regulations.

A student who fails to register in the first three weeks of the semester, without benefit of a leave of absence or permission for study in absentia, will be deemed to have withdrawn.

Students who withdraw from the College of Engineering are eligible to apply for admission to one of the other six colleges at Cornell. The intrauniversity transfer process should be followed.

A student who has withdrawn and subsequently wishes to return must make a formal application for readmission. This is rarely granted. It is subject to a review of the student's academic background and depends on available space in the college and in the student's major.

**Required withdrawal:** Students are required to withdraw from the college only when their overall record indicates that they are either incapable of completing the program or not sufficiently motivated to do so. This action withdraws them only from the College of Engineering and does not, in and of itself, adversely affect their ability to transfer and complete a degree in one of the other colleges in the university.

## ENGINEERING MAJORS

This section describes the majors in the College of Engineering: the programs in which an undergraduate can study to obtain a B.S. degree.

A basic requirement of any major is a GPA $\geq$ 2.0. Most majors have a higher GPA requirement and may have other requirements.

### Honors Program within Majors

Many of the engineering majors supplement the major with an honors program.

#### Eligibility

The B.S. degree with honors is granted to engineering students who, *in addition* to having completed the requirements for a B.S. degree in a major, satisfactorily complete the honors program in the major and are recommended for the degree by the honors committee of that major. To enter an honors program, the student must be on track to graduate with distinction, and a student who does not stay on track to graduate with distinction is dropped from the honors program.

Courses taken to satisfy the honors requirement may not be used to satisfy B.S. degree requirements. At least 9 extra credit hours are required, and a student must be in the program for at least two semesters before graduation.

No research, independent study, or teaching for which the student is paid may be counted toward the honors program.

#### Procedures

An applicant to the honors program in a major must have an honors advisor: a faculty member from that major who will supervise the honors program and direct the research or project. The honors advisor need not be the student's advisor in the major.

The application for the honors program should be a letter from the student that describes the proposed honors program in detail and includes the explicit approval of the honors advisor.

Students must complete a written application no later than the beginning of the first semester of their senior year, but they are encouraged to make arrangements with the honors advisor during the second semester of their junior year. Each major may place further constraints on timing.

#### Major-Specific Information

Each major defines the content of the honors program and may also place other requirements on the program, in terms of timing, content, and procedures. Information is given within the description of the individual majors.

## BIOLOGICAL ENGINEERING

Offered by the Department of Biological and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255-2173, www.bee.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Biological and environmental engineering (BEE) programs address three great challenges facing humanity today: ensuring an adequate and safe food supply in an era of expanding world population; protecting and remediating the world's natural resources, including water, soil, air, biodiversity, and energy; and developing engineering systems that monitor, replace, or intervene in the mechanisms of living organisms. The biological engineering (BE) major has a unique focus on biological systems, including the environment, which is realized through a combination of fundamental engineering sciences, biology, engineering applications and design courses, and liberal studies.

Students interested in the BE major should have a strong aptitude for the sciences and math and an interest in the complex social issues that surround technology.

Students take courses in math, engineering, statistics, computing, physics, chemistry, basic and advanced biology, fundamental engineering sciences (mechanics, thermodynamics, fluid mechanics, and transport processes), and engineering design. Students select upper-level engineering courses in subjects that include bioprocessing, soil and water management, biotechnology applications, bioinstrumentation, engineering aspects of animal physiology, environmental systems analysis, sustainable energy, and waste management and disposal. Students may further strengthen their programs by completing a minor or a second engineering major. Students planning for medical school also take additional lab-based courses in chemistry and biology. Throughout the curriculum, emphasis is placed on communications and teamwork skills, and all students complete a capstone design project.

Career opportunities cover the spectrum of self-employment, private industry, public agencies, educational institutions, and graduate and professional programs in engineering and science, as well as professional fields like medicine, business, and law. In recent years, graduates have pursued careers in consulting, biotechnology, the pharmaceutical industry, biomedical engineering, management, and international development.

The living world is all around us and within us. The biological revolution continues, and it has given rise to a growing demand for engineers who have studied biology, who have strong math and science skills, who can communicate effectively, and who are sensitive to the needs of people and interested in the challenges facing society. The Biological Engineering major is designed to educate the next generation of engineers to meet these challenges.

The academic requirements* for students majoring in Biological Engineering are outlined below.

| *Basic Subjects* | *Credits* |
|---|---|
| MATH 1910**, 1920, 2930, 2940 | |
| Calculus for Engineers and Engineering Mathematics | 16 |
| PHYS 1112, 2213 | 8 |
| CHEM 2090* General Chemistry | 4 |
| CHEM 1570 or 3570* Organic Chemistry | 3 |
| BEE 1510 Introduction to Computer Programming or CS 1112, and CS 1130 | 5 |
| Biological Sciences* | 15 |
| Introductory (BIOG 1101–1104 recommended) | 8 |
| Biological science electives at or above 2000 level to complete 15 credits | |
| Biochemistry or Microbiology required | |
| *Major-required courses* | 46 |
| BEE 1200 The BEE Experience or ENGRG 1050 (counted as an advisor-approved elective) | 1 |
| ENGRD 2020 Mechanics of Solids | 4 |
| BEE 2600 Biological Engineering Analysis or BEE 2510 Environmental Engineering Analysis | 3 |
| BEE 3500 Biological and Environmental Transport Processes | 3 |
| BEE 2220 or ENGRD 2210 Thermodynamics | 3 |
| ENGRD 2700 or CEE 3040 Engineering Statistics and Probability | 3–4 |
| BEE 3310 or CEE 3310 Fluid Mechanics | 4 |

Concentration courses (three courses, minimum of 9 credits, chosen from one of the following BE concentrations): Biomedical Engineering, Bioprocess Engineering, or Bio-Environmental Engineering.***

Major-approved Engineering Electives (one course must be a BEE Capstone course and one course must be a BEE lab experience course:)*** (Engineering courses at 2000 level or above to bring the total of required plus engineering electives to complete 46 credits)

| | |
|---|---|
| Liberal studies (two first-year writing seminars and six liberal studies electives) | 24 |
| Advisor-approved electives | 6 |
| Total (minimum) | 127 |

*Basic accredited curriculum. See also the section on minors. Information on preprofessional study for medicine, dentistry, and veterinary medicine is available at www.career.cornell.edu.

** Students must have a competency in calculus equivalent to MATH 1110 before they attempt MATH 1910.

*** See department web page for a current list of approved courses.

Students must satisfy the College of Engineering Technical Writing requirement by including one of the approved courses in their program of study.

### Biological Engineering Honors Program

The B.S. degree with honors is granted to biological engineering majors who graduate with distinction from the College of Engineering and satisfy the Honors requirements given at the beginning of the section "Engineering Majors."

The Honors program requires completion of 9 credits beyond the B.S. degree requirements drawn from the following, with at least 6 credits in the first category:

1. A significant research experience or honors project under the supervision of a BEE faculty member using BEE 4991 BE Honors Research completed in their senior year. A written senior honors thesis must be submitted as part of this component.
2. A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the department under BEE 4980 Undergraduate Teaching.
3. Advanced or graduate courses. These additional courses must be technical in nature, i.e., in engineering, math, biology, chemistry, and physics at the 4000+ and graduate level.

## CHEMICAL ENGINEERING

Offered by the School of Chemical and Biomolecular Engineering

Contact: 120 Olin Hall, 255-8656, www.cheme.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

The undergraduate major in chemical engineering comprises a coordinated sequence of courses beginning in the sophomore year and extending through the fourth year. Students who plan to enter the major take CHEM 2080 during the freshman year. The program for the last three years is as follows:

| *Semester 3* | *Credits* |
|---|---|
| MATH 2930 Engineering Mathematics | 4 |
| PHYS 2213 Physics II, Heat/ Electromagnetism | 4 |
| CHEM 3890 Physical Chemistry I (engineering distribution) | 4 |
| ENGRD 2190 Mass and Energy Balances (engineering distribution) | 3 |
| Liberal Studies Distribution | 3 |
| *Semester 4* | |
| MATH 2940 Linear Algebra for Engineers | 4 |
| CHEME 3230 Fluid Mechanics | 3 |
| CHEM 3900 Honors Physical Chemistry II (major) | |
| CHEM 2900 Introductory Physical Chemistry Laboratory (major) | 6 |
| Biology elective* | 3 |
| Liberal Studies Distribution | 3 |
| *Semester 5* | |
| CS 1130 or CS 1132 Transition to MATLAB | 1 |
| CHEM 3570 Organic Chemistry for the Life Sciences | 3 |
| CHEM 2510 Introduction to Experimental Organic Chemistry | 2 |
| CHEME 3130 Chemical Engineering Thermodynamics | 3 |
| CHEME 3240 Heat and Mass Transfer | 3 |
| Liberal Studies Distribution | 3 |
| *Semester 6* | |
| Advanced science elective** | 3 |
| CHEME 3010 Nonresident Lectures | 1 |
| CHEME 3320 Analysis of Separation Processes | 3 |
| CHEME 3720 Introduction to Process Dynamics and Control | 2 |
| CHEME 3900 Reaction Kinetics and Reactor Design | 3 |
| Liberal Studies Distribution | 3 |
| *Semester 7* | |
| CHEME 4320 Chemical Engineering | |
| Laboratory | 4 |
| Electives*** | 9 |
| Liberal Studies Distribution | 3 |
| *Semester 8* | |
| CHEME 4620 Chemical Process Design | 4 |
| Liberal Studies Distribution | 3 |
| Electives*** | 3 |
| Approved elective | 3 |

*Every student must complete one of the five following options for the biology elective: (1) CHEME 2880 Biomolecular Engineering: Fundamentals and Applications. (2) advanced placement: a score of 5 on the CEEB AP exam or a score of 7 on the IB Higher Level exam. (3) 4 credits of a pre-med biology sequence: BIOG 1101 Biological Sciences, Lec (fall, 2 credits) and BIOG 1103 Biological Sciences, Lab (fall, 2 credits), BIOG 1102 Biological Sciences, Lec (spring, 2 credits) and BIOG 1104 Biological Sciences, Lab (spring, 2 credits), BIOG 1105 Introductory Biology (fall, 4 credits), BIOG 1106 Introductory Biology (spring, 4 credits), BIOG 1107 General Biology (summer, first half of eight-week session, 4 credits) or BIOG 1108 General Biology (summer, second half of eight-week session, 4 credits). (4) 3 credits of microbiology: BIOMI 2900 General Microbiology (fall, spring, or summer six-week session, 3 credits). (5) 4 credits of biochemistry: BIOBM 3300 Principles of Biochemistry, Individual Instruction (fall or spring, 4 credits) or BIOBM 3330 Principles of Biochemistry: Proteins, Metabolism, and Molecular Biology (summer six-week session, 4 credits). (6) 5 credits of biochemistry: BIOBM 3310 Principles of Biochemistry: Proteins and Metabolism (fall, 3 credits) and BIOBM 3320 Principles of Biochemistry: Molecular Biology (spring, 2 credits).

**Advanced science electives include BIOMI 2900 General Microbiology Lectures; BIOBM 3300, 3310, 3320, and 3330 Principles of Biochemistry; BME 3010 (CHEME 4010) Molecular Principles of Biomedical Engineering; BME 3020 (CHEME 4020) Cellular Principles of Biomedical Engineering; CEE 4510 Microbiology for Environmental Engineering; CEE 6540 Aquatic Chemistry; CHEME 4700 Process Control Strategies; CHEME 4800 Chemical Processing of Electronic Materials; CHEME 4810 (BME 4810) Biomedical Engineering; CHEME 4840 Microchemical and Microfluidic Systems; CHEME 5200 An Overview of Chemical Processing; CHEME 5201 Introduction to Biomedical Engineering Module; CHEME 5202 Introduction to Electronic Materials Processing Module; CHEME 5203 Introduction to Polymer Processing; CHEME 5204 Turbo Machinery Applications; CHEME 5205 Chemical Engineering Tools and Equipment; CHEME 5207 Introduction to Petroleum Refining; CHEME 5208 Renewable Resources from Agriculture; CHEME 5430 Bioprocess Engineering; CHEME 5640 Design of Chemical Reactors; CHEME 6310 (BME 6310) Engineering Principles for Drug Delivery; CHEME 6400 Polymeric Materials; CHEME 6440 Aerosols and Colloids; CHEME 6610 Air Pollution Control; FDSC 4170 Food Chemistry I; MAE 4231 Intermediate Fluid Dynamics; MSE 2060 Atomic and Molecular Structure of Matter; MSE 3050 Electronic, Magnetic, and Dielectric Properties of Materials; MSE 5210 Properties of Solid Polymers; MSE 5240 Materials Chemistry of Synthetic Polymeric Materials; MSE 5310 Introduction to Ceramics; MSE 5410 (ECE 5360) Nanofabrication for M. Eng.; TAM 3100 Advanced Engineering Analysis I; TAM 3110 Advanced Engineering Analysis II; any AEP course numbered 3330 or above; any CHEM course numbered 3010 or above; any PHYS course numbered 300 or above.

***The electives in semesters 7 and 8 comprise 6 credits of major-approved electives and 6 credits of advanced CHEME electives. Advanced CHEME electives include any CHEME course at the 4000+ level except CHEME 4900, 4990, 5200–5209, and 5720.

# CIVIL ENGINEERING

Offered by the School of Civil and Environmental Engineering

Contact: 221 Hollister Hall, 255-3412, www.cee.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

While it is not necessary to do so, students may concentrate in environmental engineering, environmental fluid mechanics and hydrology, geotechnical engineering, structural engineering, transportation, or water resource systems.

## Admission Requirements

Students planning to affiliate with this major must complete ENGRD 2020 Mechanics of Solids (or, for students following the Environmental Concentration, ENGRD 2510) with at least C–. It is strongly recommended that ENGRD 2020 be taken as an engineering distribution during the first semester of the sophomore year.

### Engineering Distribution Courses

Majors are required to take ENGRD 2020 Mechanics of Solids as an engineering distribution course. For the second engineering distribution course, one of the following is recommended:

ENGRD 2610 Introduction to Mechanical Properties of Materials, for students interested in structural engineering and geotechnical engineering.

ENGRD 2210 Thermodynamics, for students interested in fluid mechanics and hydraulics/hydrology.

ENGRD 2110 Object Oriented Programming and Data Structures, for students interested in transportation.

ENGRD 2510 Engineering for a Sustainable Society, for students interested in environmental engineering.

## Major Program

Students may substitute CHEM 2080 or CHEM 1570 for PHYS 2214. The following nine courses are required in addition to those required for the Common Curriculum. (Students interested in the Environmental Concentration should follow the course requirements for the Environmental Engineering Major and should refer to the CEE Undergraduate Handbook for requirements specific to CE majors. CE majors should take CEE 3410.)

| *Core Courses* | *Credits* |
|---|---|
| ENGRD 2030 Dynamics* or CEE 4780 Structural Dynamics | 3 |
| ENGRD 3200 Engineering Computation* | 3 |
| CEE 3040 Uncertainty Analysis in Engineering† | 4 |
| CEE 3230 Engineering Economics and Management | 3 |
| CEE 3310 Fluid Mechanics | 4 |
| CEE 3410 Introduction to Geotechnical Engineering and Analysis | 4 |
| CEE 3510 Environmental Quality Engineering** | 3 |
| CEE 3610 Introduction to Transportation Engineering** | 3 |
| CEE 3710 Structural Modeling and Behavior | 4 |

Additional requirements include a set of two major-approved electives and three design electives from a list of approved courses that is available in the school office. In addition, students must complete one technical communications course from among the courses designated ENGRC or approved communications courses. If the technical communications course also fulfills another requirement (liberal studies major–approved elective, etc.), then an additional advisor-approved elective must be taken.

*ENGRD 2030 and ENGRD 3200 can be used to satisfy a major requirement. If a student elects to use one of these courses as a second distribution course, the student must take an additional major-approved elective to fulfill the core course requirements.

†ENGRD 2700 may be substituted (by petition) for CEE 3040 in the major, but only if ENGRD 2700 is taken before affiliation, or in some special cases where co-op or study abroad programs necessitate such a substitution.

**Students may substitute CEE 3720 or CEE 4710 for either CEE 3510 or 3610, if they also complete either CEE 4730 or 4740. However, CEE 3720 or CEE 4710 then counts as a core course only and not as a CEE design course or major-approved elective. Students may also substitute CEE 4610 for CEE 3510 if they also take two of these three courses: CEE 4630, CEE 4640 and 4650. However, then CEE 4610 counts as a core course only and not as a CEE design course or major-approved elective.

## Civil Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section “Engineering Majors” as well as the following requirements.

The 9 credits beyond the B.S. degree requirements shall be drawn from the following components (with no fewer than 2 credits in any selected component):

1. A significant research experience or honors project under the direct supervision of a CEE faculty member using CEE 4000 Senior Honors Thesis (1–6 credits per semester). A significant written report or senior honors thesis must be submitted as part of this component. Letter grades only.
2. A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the College of Engineering, i.e., ENGRG 4700 Peer Teaching in Engineering or CEE 4010 Undergraduate Teaching in CEE (1–3 credits per semester).
3. Advanced or graduate courses at the 5000 level or above.

### Procedures

Application to the program shall be a registration form for CEE 4000 and a letter from the student describing the specific proposed honors program and including the explicit approval of the major advisor and the honors advisor. Each program must be approved by the CEE Curriculum Committee, although the committee may delegate approval authority to the associate director for all but unusual proposals.

# COMPUTER SCIENCE

Offered by the Department of Computer Science

Contact: 303 Upson Hall, 255-0982, www.cs.cornell.edu

The Department of Computer Science is affiliated with both the College of Arts and Sciences and the College of Engineering. Students in either college may major in computer science.

Computer science majors take courses in algorithms, data structures, logic, programming languages, scientific computing, systems, and theory. Electives in artificial intelligence, computer graphics, computer vision, databases, multimedia, and networks are also possible. Requirements include:

- MATH 1910, 1920, and 2940
- three courses in introductory computing; either CS 1110, CS 1132, CS 2110 or CS 1112, CS 1030, CS 2110
- a 1-credit project (CS 2111)
- a seven-course computer science core (CS 2800, 3110, 3410, or 3420; one of 3220, 4210, or 4220; 3810, 4410, and 4820)
- two 4000+ level computer science electives (CS 4999 not allowed)
- a computer science project course (CS 4121, 4321, 4411, 4450, 4621, 4701, 5150, 5410, or 6670)
- a math elective course (e.g., ENGRD 2700, MATH 2930, MATH 3000+, TAM 3100)
- two 3000+ level courses (major-approved electives) that are technical in nature
- a three-course specialization in a topic area other than computer science, all numbered 3000 level or greater

All the major electives described above must be courses of at least 3 credits, with the exception of the CS project course, which is at least 2 credits.

The program is broad and rigorous, but it is structured in a way that supports in-depth study of outside areas. Intelligent course selection can set the stage for graduate study or employment in any technical area or any professional area such as business, law, or medicine. With the advisor, the computer science major is expected to put together a coherent program of study that supports career objectives and is true to the aims of a liberal education.

### Computer Science Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Engineering Majors" with a set of coherent courses and research activities that satisfy the following requirements.

1. at least one CS course (at least 3 credit hours) at or above the 5000 level with a grade of A– or better (no seminars)
2. at least two 3-credit semesters of CS 4999 (independent research), with grades of A– or better each semester

Honors determinations are made during the senior year. Students wanting to be considered for the honors program should notify the undergraduate office in the Department of Computer Science at ugrad@cs.cornell.edu. The subject line for this message should read "HONORS TRACK". Address related questions to the same e-mail address; call or stop by 303 Upson Hall, 255-0982; or visit www.cs.cornell.edu/ugrad for more information on eligibility.

## ELECTRICAL AND COMPUTER ENGINEERING

Offered by the School of Electrical and Computer Engineering

Contact: Student Services Office, 223 Phillips Hall, 255-4309, www.ece.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

The Electrical and Computer Engineering major (ECE), leading to a B.S. degree, provides a foundation that reflects the broad scope of this engineering discipline.

Concentrations include computer architecture and organization, digital systems and computer vision; power systems control; communications, networks, information theory and coding, signal processing and optimization; electronic circuits, VLSI, solid state physics and devices, MEMs, nanotechnology, lasers and optoelectronics; electromagnetics, radiophysics, space sciences, and plasmas.

ECE majors must take ECE/ENGRD 2300 as an engineering distribution course and are encouraged, but not required, to take ENGRD 2110 as the other engineering distribution course. The major normally begins in the spring of the sophomore year. Of the courses listed below, only ENGRD/ECE 2100 and ECE/ENGRD 2300 are taught in both the fall and spring semesters.

| *Course* | *Credits* |
|---|---|
| **Major-required courses** | |
| ECE/ENGRD 2100 Introduction to Circuits for Electrical and Computer Engineers | 4 |
| ECE 2200 Signals and Information | 4 |
| ECE 3030 Electromagnetic Fields and Waves | 4 |
| ECE 3100 Introduction to Probability and Random Signals | 4 |
| ECE 3140/CS 3420 or 3410 Computer Organization | 4 |
| ECE 3150 Introduction to Microelectronics | 4 |
| **Major-approved electives** *(29-credit minimum in the following categories)* | |
| Advanced ECE electives† | (six lecture courses) |
| Outside ECE electives‡ | 9 minimum credits |
| Total minimum major credits | 53 |

ECE 3100 satisfies the major requirement of probability and statistics.

†These electives must include two 4000-level Electrical and Computer Engineering culminating design experience (CDE) courses and at least two additional courses at the 4000 level or above. The remaining electives may not include independent project courses, such as ECE 3910, 3920, 4910, or 4920, and must be at the 3000 level or above in Electrical and Computer Engineering.

Courses that meet the CDE requirement are described in the *Engineering Undergraduate Handbook*. The list changes frequently. An updated list of courses that meet the CDE requirements will be posted each semester on the bulletin board outside 222 Phillips Hall. All courses must have a college-level prerequisite.

‡Must include one course at the 3000 level or above (see *Electrical and Computer Engineering Web Handbook* for details).

Undergraduate concentration is achieved through the various Electrical and Computer Engineering elective courses, as well as other courses in related technical fields within engineering, math, the physical sciences, and the analytical biological sciences. The School of Electrical and Computer Engineering offers more than 30 courses that are commonly taken as electives by undergraduates.

### Academic Standards

Majors in Electrical and Computer Engineering are expected to meet the following academic standards:

1. GPA $\geq$ 2.3 every semester.
2. At least C– in all courses used to satisfy degree requirements in the major or that serve as a prerequisite for a subsequent Electrical and Computer Engineering course.
3. Satisfactory completion of MATH 2940, PHYS 2214, and two of ENGRD/ECE 2100, ECE 2200, and ENGRD/ECE 2300 by the end of the sophomore year and adequate progress toward the degree in subsequent semesters.

### Electrical and Computer Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Engineering Majors" as well as the following requirements:

Students must apply during the first three weeks of the sixth semester. They must achieve at least a B in the three required courses taken for honors designation.

#### Honors Seminar

Prospective honors students must take an honors seminar in the spring semester of their junior year, for a letter grade and 2 credits. The honors seminar consists of a weekly series of introductory research lectures by ECE faculty members. Each honors seminar enrollee will write two short papers on topics covered in the lecture series. Many ECE faculty members will give a lecture or short series of lectures as part of the honors seminar.

#### Honors Project

A student in the honors program is required to accumulate at least 3 credit hours from a senior-year honors project with an ECE faculty member, consisting of either design, research, or directed reading at the 400 level. All honors projects emphasize the development of communication skills. Design- and reading-oriented honors projects explicitly require a written submission summarizing and concluding the project.

#### Additional Course Work

At least 3 credit hours are required of advanced (senior level) ECE course work that has at least a 300-level prerequisite. These credit hours are in addition to any credit hours required as part of the ECE major.

The requirement for at least 9 credits over and above the 130 credits required for a B.S.

degree means that an honors degree requires 139 credit hours.

## ENGINEERING PHYSICS

Offered by the School of Applied and Engineering Physics

Contact: 212 Clark Hall, 255-5198, www.aep.cornell.edu

The engineering physics (EP) major is designed for students who want to pursue careers of research or development in applied science or advanced technology and engineering. Its distinguishing feature is a focus on the physics and math fundamentals, both experimental and theoretical, that are at the base of modern engineering and research and have a broad applicability in these areas. By choosing areas of concentration within this major, students may combine this physics base with a good background in a conventional area of engineering or applied science.

The industrial demand for EP B.S. graduates is high, and many students go directly to industrial positions where they work in a variety of engineering or developmental areas that either combine, or are in the realm of, various more conventional areas of engineering. Recent examples include bioengineering, computer technology, electronic-circuit and instrumentation design, energy conversion, environmental engineering, geological analysis, laser and optical technology, microwave technology, nuclear technology, software engineering, solid-state-device development, technical management, and financial consulting. A number of EP graduates go on for advanced study in all areas of basic and applied physics as well as in a diverse range of areas in advanced science and engineering. Examples include applied physics, astrophysics, atmospheric sciences, biophysics, cell biology, computer science and engineering, electrical engineering, environmental science, fluid mechanics, geotechnology, laser optics, materials science and engineering, mathematics, mechanical engineering, medical physics, medicine, nuclear engineering, plasma physics, oceanography, and physics. The major can also serve as an excellent preparation for medical school, business school, or specialization in patent law.

The EP major fosters this breadth of opportunity because it both stresses the fundamentals of science and engineering and gives the student direct exposure to the application of these fundamentals. Laboratory experimentation is emphasized, and ample opportunity for innovative design is provided. Examples are ENGRI/AEP 1110 Lasers and Photonics; ENGRI/AEP 1200 Introduction to Nanoscience and Nanoengineering; ENGRD/AEP 2640 Computer-Instrumentation Design (a recommended sophomore engineering distribution course); AEP 3330 Modern Experimental Optics (a junior/senior course); AEP 3630 Electronic Circuits (a sophomore/junior course); PHYS 4410 Advanced Experimental Physics; and AEP 4380 Computational Engineering Physics (a senior computer laboratory).

Students who plan to affiliate with the EP major are advised to arrange their common curriculum with their developing career goals in mind. They are encouraged to take PHYS 1112 or 1116 during their first semester (if AP credits permit) and to satisfy the technical writing requirement with the engineering distribution course ENGRD 2640. EP students need to take only one engineering distribution course, since AEP 3330, taken in the junior year, counts as the second one. EP students are advised to take AEP 3630 (taking ECE 2100 and 2300, 4 credits each, can satisfy AEP 3630. Count ECE 2100 as an approved elective and ECE 2300 as AEP 3630) in the spring semester of the sophomore year. Students with one semester of advanced placement in math and who have received at least A– in MATH 1920 may wish to explore accelerating their math requirements so as to enroll in AEP 3210 and 3220 in the sophomore year. For advice on this option, consult with the AEP associate director.

In addition to the requirements of the Engineering Common Curriculum,* the major requirements are as follows:

| *Course* | *Credits* |
|---|---|
| AEP 3330 Mechanics of Particles and Solid Bodies | 4 |
| AEP 3550 Intermediate Electromagnetism | 2 |
| AEP 3560 Intermediate Electrodynamics | 4 |
| AEP 3610 Introductory Quantum Mechanics | 2 |
| AEP 3620 Intermediate Quantum Mechanics | 4 |
| AEP 3630 Electronic Circuits | 4 |
| AEP 4230 Statistical Thermodynamics | 4 |
| AEP 4340 Continuum Physics | 4 |
| PHYS 4410 Advanced Experimental Physics | 4 |
| AEP 3210 Mathematical Physics I | 4 |
| AEP 3220 Mathematical Physics II | 4 |

Six major-approved electives (18–23 credits), of which five must be technical upper-level courses (300 or above).

Total major credits=58 credit hours minimum

*The Engineering Common Curriculum suggests that freshmen take only four courses each semester. This course load is fully consistent with the requirements of the EP major, but freshmen with strong preparation are encouraged to consider taking an additional course during one or both semesters so that they may have additional flexibility in developing a strong, individualized educational program in their later years and for allowing options such as a semester or year abroad or early graduation.

Two of the 4 credits of PHYS 4410 required for the B.S. degree in EP can be satisfied by completing AEP/PHYS 3330 or ASTRO 4410. The remaining 2 credits of PHYS 4410 can then be satisfied by taking PHYS 4400 for 2 credits, provided that the experiments completed in PHYS 4400 do not overlap with those in AEP/PHYS 3330 or ASTRO 4410. (A list of experiments that are not appropriate will be prepared by AEP faculty and made available in the AEP office.) If a student chooses this option, AEP/PHYS 3330 or ASTRO 4410 may also count as a technical elective, provided the remaining three technical electives are 4 credits each.

**Choosing elective courses.** The EP major provides the students with a strong opportunity to develop individualized programs of study to meet their particular educational and career goals. These can include the pursuit of a dual major or the development of a broad expertise in a number of advanced technical and scientific areas. With at least seven electives in the sophomore, junior, and senior years, EP majors are encouraged to work closely with their advisor to develop a coherent academic program that is consistent with those goals. For students who look toward an industrial position after graduation, the electives should be chosen to widen their background in a specific area of practical engineering. A different set of electives can be selected as preparation for medical, law, or business school. For students who plan on graduate studies, the electives provide an excellent opportunity to explore upper-level and graduate courses and to prepare for graduate study in any one of a number of fields. Various programs are described in a special brochure available from the School of AEP, Clark Hall. Students are advised to consult with their EP advisor, a professor active in their area of interest, or with the associate director of the school.

Electives need not be all formal course work: qualified students are encouraged to undertake independent study under the direction of a member of the faculty (AEP 4900). This may include research or design projects in areas in which faculty members are active.

The variety of course offerings and many electives provide flexibility in scheduling. If scheduling conflicts arise, the school may allow substitution of courses nearly equivalent to the listed required courses.

#### Academic Standing

Students are expected to pass every course in which they are registered, to earn at least C– in specifically required courses, and to attain a semester GPA $\geq$ 2.3 each semester.

### Engineering Physics Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section “Engineering Majors” as well as the following requirements.

1. At least 8 credits of major-approved electives at the 4000 level or higher with at least A– in each, not counting credits given for item 2.
2. Two semesters of AEP 4900 or an equivalent course, with at least 2 credits the first semester and 4 credits the second. The student will complete an independent research project or senior thesis under the supervision of an engineering or science faculty member. The level of work required for successful completion is to be consistent with the amount of academic credit granted.

#### Procedures

Before enrolling in AEP 4900 or the equivalent, submit a brief proposal outlining the topic and scope of the project or thesis and an honors advisor’s written concurrence to the associate director for undergraduate studies. This proposal will be reviewed by the AEP Honors Committee and either approved or returned to the candidate to correct deficiencies. The proposed project or thesis is to consist of a research, development, or design project and must go beyond a literature search. The final steps in completing the honors project are a written and oral report. The written report is to be in the form of a technical paper with, for example, an abstract, introduction, methods section, results section, conclusions section, references, and figures. This report will be evaluated by the faculty supervisor and the chair of the AEP Honors Committee. Following completion of the written report, an oral report is to be presented to an audience consisting of the faculty supervisor, the chair of the Honors Committee, and at least one other departmental faculty member, along with the other honors candidates. A copy of the final report is to be given to the chair of the AEP Honors Committee. The final research project course grade will be assigned by the faculty supervisor after consultation with the chair of the Honors Committee. At least A– is required for successful completion of the honors requirement.

## ENVIRONMENTAL ENGINEERING

Offered jointly by the Department of Biological and Environmental Engineering and the School of Civil and Environmental Engineering.

Contact: 221 Hollister Hall, 255-3412, www.cee.cornell.edu, or 207 Riley-Robb Hall, 255-2173, www.bee.cornell.edu

Environmental Engineering is the study and practice of analyzing, designing, and managing natural and engineered systems in ways consistent with the maintenance or enhancement of environmental quality and sustainability. It requires the ability to predict multiple interactions and impacts among natural and engineering-system components at various spatial and temporal scales in response to alternative design and management policies. It requires a thorough understanding of the interactions among the natural environment, the constructed environment, and human activities.

Students matriculating in the College of Engineering (COE) may affiliate with this major in their second year. Students matriculating in the College of Agriculture and Life Sciences (CALS) may enroll in this major in their first semester. Students planning to graduate with this major will be taking the following courses:

**Mathematics-science core requirements**

| *Course* | *Credits* |
|---|---|
| MATH 1910, 1920, 2930, 2940 | 16 |
| PHYS 1112, 2213 | 8 |
| CHEM 2090 and 1570 | 7 |
| CS 1110, CS 1112, or BEE 1510* followed by CS 1132 or CS 1130 | 5 |
| **Introduction to engineering^^^** | **3** |
| ENGRI 1130 Water Treatment Design (recommended), or | |
| BEE 1200 The BEE Experience* (required for students matriculating in CALS) | |

**Engineering distribution courses†**

| | |
|---|---|
| ENGRD 2510 Engineering for a Sustainable Society (required) | 3 |
| ENGRD 2020, 3200, or 2210 are recommended or BIOG 1101–1103, BIOG 1105, BIOG 1107 may be used) | 3–4 |

**Major-required courses**

| *Major Courses* | | *Credits* |
|---|---|---|
| BIOG 1109 | Introductory Biology** (students may also use BIOG 1101–1103, BIOG 1102–1104, BIOG 1105, BIOG 1106, BIOG 1107, or BIOG 1110 to satisfy the biology requirement) | 3–4 |
| ENGRD 2020 | Mechanics of Solids** | 4 |
| ENGRD 3200 | Engineering Computation** | 3 |
| *or* | | |
| ENGRD 2210 | Thermodynamics** | 3 |
| CEE 3040 | Uncertainty Analysis in Engineering*** | 4 |
| CEE 3310 | Fluid Mechanics | 4 |
| Earth Science (one from the following list): | | 3–4 |
| CEE 3410 | Introduction to Geotechnical Engineering and Analysis | |
| *or* | | |
| EAS 3030 | Introduction to Biogeochemistry | |
| *or* | | |
| CSS 3650 | Environmental Chemistry: Soil, Air, and Water | |
| *or* | | |
| BEE 3710 | Physical Hydrology for Ecosystems | |
| CEE 3510 | Environmental Quality Engineering | 3 |
| CEE 4510 | Microbiology for Environmental Engineering†† | 3 |
| Laboratory Course (one from the following list): | | |
| CEE 4530 | Lab Research in Environmental Engineering | 3 |
| *or* | | |
| BEE 4270 | Water Sampling and Measurement | |
| *or* | | |
| BEE 4730 | Watershed Engineering | |
| *or* | | |
| CEE 4370 | Experimental Methods in Fluid Dynamics | |
| BEE 4750 | Environmental Systems Analysis | 3–4 |
| Engineering Economics: | | 3–4 |
| CEE 3230 | Engineering Economics and Management | |
| *or* | | |
| BEE 4890 | Entrepreneurial Management for Engineers | |

**Electives**

| | |
|---|---|
| Technical communications course††† (ENGRC 3350 or 3500; COMM 2600, 2630, or 3520 in liberal studies category; or BEE 4930 taken with BEE 4730 or BEE 4890 or BEE 4530) | 4–5 |
| Three Environmental design electives chosen from the list of approved courses | 9-credit minimum‡ |
| Two major-approved engineering electives to complete total credit requirement‡‡ | 6 |
| First-year writing seminar | 6 |
| Two approved electives | 6 |
| Liberal studies | 18 |
| Total credits (minimum) | 126 |

^^^COE matriculated students must complete one ENGRI 1XXX course their first year. CALS matriculated students may complete BEE 1510 and BEE 1200 to meet the requirement.

*BEE 1510 and 1200 together (5 credits) satisfy the ENGRI requirement for CALS–matriculated first-year students. Students using BEE 1200 and BEE 1510 to satisfy the ENGRI requirement must make up the 2-credit difference with engineering course work.

**Students using this course as a second engineering distribution must take an additional major-approved elective. BIOG 1090 is not an engineering distribution course.

***ENGRD 2700 (f,s,3) may be accepted (by petition) to substitute for CEE 3040 if taken prior to affiliation with the Environmental Engineering major or if necessary because of scheduling conflicts caused by co-op or study abroad.

†Students must complete two ENGRD courses.

††Students may take BIOMI 2900 Introduction to Microbiology in place of CEE 4510.

†††If the course fulfilling the technical writing requirement also fulfills another requirement (e.g., liberal studies, major-approved elective), then it may be used to satisfy both requirements.

‡To be chosen from a list of design courses. Students are encouraged to take CEE 4520, CEE 4540, or BEE 4730.

‡‡The list of suggested courses covers the areas of environmental engineering, hydraulics/hydrology, environmental systems engineering, geotechnical engineering, remote sensing, air pollution, and renewable energy systems. The respective lists are available at the departmental offices.

### Environmental Engineering Honors Program

Students interested in pursuing an honors program should contact the undergraduate program director of Biological and Environmental Engineering or the associate director of Civil and Environmental Engineering for information on the program requirements.

## INDEPENDENT MAJOR

Offered by the Independent Major Committee

Contact: Associate Dean for Undergraduate Programs, 167 Olin Hall, 255-8240

The independent major is designed for students whose educational objectives cannot be met by one of the regular majors. This major consists of an engineering primary area (32 credits) and an educationally related secondary area (16 credits). The primary area may be in any subject area offered by schools or departments of the college; the secondary area may be in a second engineering subject area or in a logically connected nonengineering area. The combination must form an engineering education in scope and substance and should include engineering design and synthesis as well as engineering sciences. Each program includes the normally required common-curriculum requirements and approved electives.

Students should apply to the independent major during the sophomore year. A student should seek assistance in developing a coherent program from professors in the proposed primary and secondary areas (an advisor in each area is required). The program must also be approved by the Independent Major Committee. If approved, the program is the curricular contract to which the student must adhere.

Because no single standardized curriculum exists, the independent major is not accredited by ABET. Independent major students who intend to seek legal licensing as a Professional Engineer should be aware that this nonaccredited degree program will require additional education, work, and/or experience to qualify for eligibility to take the Fundamentals of Engineering examination and may affect acceptance into engineering graduate programs.

## INFORMATION SCIENCE, SYSTEMS, AND TECHNOLOGY

Offered jointly by the Department of Computer Science and the School of Operations Research and Information Engineering

Contact: 303 Upson Hall, 255-9837, www.infosci.cornell.edu, or 202 Rhodes Hall, 255-5088, www.orie.cornell.edu

Digital information technologies have become pervasive in science, engineering, manufacturing, business, finance, culture, law, and government, dramatically changing the way people work and live. The proliferation and significance of these new technologies demands a new focus in engineering education—one that remains rigorous and technically oriented but is simultaneously devoted to integrating engineering design, theory, and practice within the social and organizational contexts in which these complex digital information systems are employed.

The information science, systems, and technology (ISST) major studies the design and management of complex information systems. Just as structural engineers and nanofabricators use physics at radically different scales, so also there is a scale difference between the focus of the ISST major and the more traditional, look-under-the-hood majors in computer science and operations research and industrial engineering. Rather than focusing on the computing and communication technologies that underlie digital information systems, the ISST major emphasizes information systems engineering in broad application contexts, where issues at the confluence of information science, technology, and management are the primary concerns.

The ISST major has two options. The management science option educates students in methods for quantitative decision making and their application to information technology as well as the broader role that information technology plays in making these methods effective. Students in the information science option will obtain advanced training in methods for the creation, representation, organization, access, and analysis of information in digital form.

Note: Students may not double major in both CS and ISST or ORIE and ISST.

**Engineering distribution courses**

Majors are required to take ENGRD 2700 Basic Engineering Probability and Statistics as an engineering distribution course. ENGRD 2110 Computers and Programming is required for the major and is recommended as the second engineering distribution course.

**Major program**

| *Core courses* | *Credits* |
|---|---|
| Probability, Statistics, and Optimization | |
| ORIE 3300 Optimization I | 3 |
| ORIE 3500 Engineering Probability and Statistics II | 3 |
| Information Systems | |
| INFO 2300 Intermediate Design and Programming for the Web | 3 |
| ORIE 3800 Information Systems and Analysis | 3 |
| INFO 3300 Data-Driven Web Applications | 3 |
| Economic, Organizational, and Social Context | |
| ECON 3010 or 3130 Microeconomics | 3 |
| One of: | |
| ILROB 1750 Behavior, Values, and Performance | 3 |
| INFO 2450 Psychology of Social Computing | 3 |
| ENGRC 3350 Communications for Engineering Majors | 3 |

**Requirements for the information science option:**

1. Three courses from Information Systems (Area II below).
2. One course from Mathematical Modeling in IT (Area III).
3. Three electives, all from either Human-Centered Systems (Area V) or Social Systems (Area VI).
4. Two electives from any of the six areas (INFO 4900 may be used to fulfill one of these electives).

**Requirements for the management science option:**

1. Four courses from Mathematical Models in Management Science (Area I).
2. Three electives, one from Information Systems (Area II) and two from the union of Mathematical Modeling in IT (Area III) and Information Technology Management Solutions (Area IV).
3. Two electives from any of the six areas (INFO 4900 may be used to fulfill one of these electives).

**Area I. Mathematical Models in Management Science**

ORIE 3150 Financial and Managerial Accounting

ORIE 3510 Introductory Engineering Stochastic Processes I

ORIE 4580 Simulation Modeling and Analysis

ORIE 4800 Information Technology

**Area II. Information Systems**

CS 4450 Computer Networks

INFO 4300 Information Retrieval

INFO 4302 Web Information Systems

CS 4320 Introduction to Database Systems

CS 4620 Introduction to Computer Graphics

CS 4700 Foundations of Artificial Intelligence

CS 4740 Introduction to Natural Language Processing

CS 5150 Software Engineering

CS 5430 System Security

INFO 5300 Architecture of Large-Scale Information Systems

CS 5780 Empirical Methods in Machine Learning and Data Mining

**Area III. Mathematical Modeling in IT**

INFO 3720 Explorations in Artificial Intelligence

ORIE 4330 Discrete Models

ORIE 4740 Statistical Data Mining I

CS 4780 Machine Learning

ORIE 4850 Applications of Operations Research and Game Theory to IT

ECE 5620 Fundamental Information Theory

**Area IV. IT Management Solutions**

ORIE 4810 Delivering OR Solutions with Information Technology

ORIE 5126 Supply Chain Management

**Area V. Human-Centered Systems**

PSYCH/COGST 3420 Human Perceptions: Applications to Computer Graphics, Art, and Visual Display*

INFO 3450 Human-Computer Interaction Design

PSYCH 3470 Psychology of Visual Communications

INFO 3650 Technology in Collaboration

PSYCH 3800 Social Cognition*

PSYCH 4130 Information Processing: Conscious and Unconscious

PSYCH 4160 Modeling Perception and Cognition*

INFO 4400 Advanced Human-Computer Interaction Design

INFO 4450 Seminar in Computer-Mediated Communication

INFO 4500 Language and Technology

DEA 4700 Applied Ergonomic Methods

*Students who take PSYCH 3420 or 4160 may also count their prerequisite, PSYCH 2050 or 2140. Students who take PSYCH 3800 may also count PSYCH 2800. At most one of these 2000-level prerequisites can be counted.

**Area VI. Social Systems**

INFO 2040 Networks

SOC 3040 Social Networks and Social Processes

INFO 3200 New Media and Society

AEM 3220 Technology, Information, and Business Strategy*

INFO 3490 Media Technologies

INFO 3551 Computers: From the 17th Century to the Dotcom Boom

INFO 3561 Computing Cultures

INFO 3660 History and Theory of Digital Art

ECON 3680 Game Theory*

INFO 3871 The Automatic Lifestyle: Consumer Culture and Technology

STS 4111 Knowledge, Technology, and Property

ECON 4190 Economic Decisions Under Uncertainty

INFO 4290 Copyright in the Digital Age

INFO 4350 Seminar on Applications of Information Science

ORIE 4350 Introduction to Game Theory*

INFO 4144 Responsive Environments

INFO 4470 Social and Economic Data

INFO 4860 Computational Methods for Computer Networks

HADM 5574 Strategic Information Systems*

ECON 4760/4770 Decision Theory I and II

HADM 4489 The Law of the Internet and E-Commerce

INFO 5150 Culture, Law, and Politics of the Internet

*Only one of ECON 3680 and ORIE 4350 may be taken for ISST credit. Only one of AEM 3220 and HADM 5574 may be taken for ISST credit.

### Information Science, Systems, and Technology Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Engineering Majors" as well as the following requirements.

1. 3 credit hours of ISST course work at or above the 5000 level (no S–U courses; no seminars or 2-credit courses)
2. 6 credit hours of INFO 4900 independent study and research with an ISST faculty member, spread over at least two semesters, with at least A– each semester

   *or*

   3 credit hours of INFO 4900 independent study and research with an ISST faculty member and 3 credit hours of INFO 4910 teaching experience, both with grades of at least A–.

The ISST research is expected to result in a programming project or a written report (or both).

Any 5000- or 6000-level course taken to fulfill the honors requirements may not be counted toward fulfillment of the associated primary or secondary option requirements.

#### Procedures

Each program must be approved by the appropriate co-director of the ISST major, and any changes to the student's program must also be approved.

## MATERIALS SCIENCE AND ENGINEERING

Offered by the Department of Materials Science and Engineering

Contact: 214 Bard Hall, 255-9159, www.mse.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

Prospective majors are required to take ENGRD 2610 or 2620 before affiliating with the major. It is highly recommended that the course be taken as an engineering distribution during the sophomore year.

The major program develops a comprehensive understanding of the physics and chemistry underlying the unique properties of modern engineering materials and processes.

Students complete a series of electives to develop knowledge of materials, such as biomaterials, ceramics, polymers, and semiconductors. Application-related courses include areas of biotechnology and life science, energy and environment, materials for information science, nanotechnology, and technology management and ethics. These requirements are satisfied through a series of technical electives taken mainly in the senior year, which are selected from various engineering and science departments. Optional research involvement courses provide undergraduates with the opportunity to work with faculty members and their research groups on current projects.

The major requirements for a B.S. degree in materials science and engineering are:

1. ENGRD 2610 Mechanical Properties of Materials: From Nanodevices to Superstructures *or*

   ENGRD 2620 Electronic Materials for the Information Age
2. 13 required major courses:

   MSE 2060 Atomic and Molecular Structure of Matter

   MSE 2610 or MSE 2620 (whichever was not taken as a distribution course)

   MSE 3010 Materials Chemistry

   MSE 3030 Thermodynamics of Condensed Systems

   MSE 3040 Kinetics, Diffusion, and Phase Transformations

   MSE 3050 Electronic, Magnetic, and Dielectric Properties of Materials

   MSE 3070 Materials Design Concepts I

   MSE 3110 Junior Lab I

   MSE 3120 Junior Lab II

   MSE 4020 Mechanical Properties of Materials, Processing, and Design

   MSE 4030/4050 Senior Materials Lab I or Senior Thesis I

   MSE 4040/4060 Senior Materials Lab II or Senior Thesis II

   MSE 4070 Materials Design Concepts II
3. Two materials-related electives covering two groups of different materials
4. Three application-related electives in at least two different types of applications
5. Two of the application-related electives must be taken from outside MSE
6. One additional technical elective outside MSE

### Materials Science and Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Engineering Majors" as well as the following requirements.

1. The 9 credits (giving a total of 141) of additional courses must be technical in nature, i.e., in engineering, math, chemistry, and physics at the 4000 and graduate level, with selected courses at the 3000 level. The courses must be approved by the major advisor.
2. Senior honors thesis (MSE 4050/4060) with a grade of at least A.

## MECHANICAL ENGINEERING

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 108 Upson Hall, 255-3573, mae@cornell.edu, www.mae.cornell.edu

This major is accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET).

This major is designed to provide a broad background in the fundamentals of the discipline as well as to offer an introduction to the many professional and technical areas in which mechanical engineers work. The program covers both major streams of mechanical engineering.

(1) *Mechanical systems, design, and materials processing* is concerned with the design, analysis, testing, and manufacture of machinery, vehicles, devices, and systems. Other topics covered are computer-aided design, vibrations, control systems, and dynamics. Particular areas of concentration are mechanical systems and design, vehicle engineering, biomechanics, and engineering materials.

(2) *Engineering of fluids, energy, and heat-transfer systems* is concerned with the efficient conversion of energy, aerospace and surface transportation, the environmental impact of engineering activity (including pollutants and noise), aeronautics, and the experimental and theoretical aspects of fluid flow, heat transfer, thermodynamics, and combustion. Specific areas of concentration include aerospace engineering, energy and the environment, and thermo-fluids engineering.

During the fall semester, sophomores who plan to affiliate with the mechanical engineering major take ENGRD 2020 (also TAM 2020) as an engineering distribution course. ENGRD 2210/MAE 2210 is required for the major and is recommended as the second engineering distribution course. The Sibley School supports students who have unusual requirements, but delays or substitutions must be discussed with and receive approval from their major advisor.

The major requires 13 courses (beyond ENGRD 2020 already mentioned) and five major-approved elective courses.

**Required courses**

MAE 2120 Mechanical Properties and Selection of Engineering Materials

ENGRD 2210 Thermodynamics

MAE 2250 Mechanical Synthesis

ENGRD 2030 Dynamics

MAE 3780 Mechatronics *or* ENGRD 2100 Introduction to Electrical Circuits, Electrical and Computer Engineering, or PHYS 3360 Electronic Circuits

MAE 3230 Introductory Fluid Mechanics

MAE 3240 Heat Transfer

MAE 3250 Analysis of Mechanical and Aerospace Structures

MAE 3260 System Dynamics

MAE 3272 Mechanical Property and Performance Laboratory

MAE 4272 Fluids/Heat Transfer Laboratory

MAE 4280 Engineering Design

MAE 4291 Supervised Senior Design Experience

**Electives**

Students should use the flexibility provided by the major-approved electives, advisor-approved electives, and humanities, arts, and social sciences electives to develop a program to meet their specific goals.

**Major-approved electives**

The major includes five major-approved electives. At least three of these courses must be upper-level (3000+) MAE courses. Two of these must be a concentration of MAE's upper-level courses providing depth in a specific subject area. Standard concentrations are shown below, but students may petition for approval of two other related courses to form a custom concentration.

The standard concentrations are:

Aerospace engineering, MAE 3050, 3060, 4150, 4230, 5060, 5070

Biomechanics, MAE 4640, 4660, 5680

Energy and the environment, MAE 4020, 4230, 4490, 4580, 4590, 5010, 5430

Engineering materials, MAE 3120, 3130, 4040, 4140, 4550, 4640, 4700, 5130

Mechanical systems and design, MAE 3780*, 4150, 4170, 4700, 4770, 4780, 5200**

Thermo-fluids engineering, MAE 4230, 4490, 4530, 5010, 5430

Vehicle engineering, MAE 3050, 3060, 4140, 4250, 4490, 4860, 5060, 5070

*Students who took MAE 3780 as a required course (see above) may not use it again as a major-approved elective.

** MAE 5200 is a 2-credit course. If it is used in a concentration, another course or courses in the concentration must be selected so that the total number of credits in the concentration is 6 or greater.

One major-approved elective must be a senior design elective involving MAE 4291 "Supervised Senior Design Experience." One way to satisfy this requirement is to take a 3+ credit section of MAE 4291, directed by a faculty member as a individual or team exercise. The other option is to take a senior design elective course (MAE 4000, 4020, 4230, 4700, or 4860) along with the corresponding 1-credit section of MAE 4291.

One of the major-approved electives must be an approved upper-level math course taken after MATH 2940. The course must include some statistics. Currently, the approved courses are TAM 3100, ENGRD 2700, CEE 3040, and ENGRD 3200.

One of the major-approved electives, the "technical elective," may be any course at an appropriate level, chosen from engineering, math, or science (physics, chemistry, or biological sciences). Appropriate level is interpreted as being at a level beyond the required courses of the college curriculum. Courses in economics, business, and organizational behavior are not accepted; advisors may approve such courses as advisor-approved electives.

MAE 4980 may not be used as a major-approved elective.

**Advisor-approved electives**

To maximize flexibility (i.e., the option for study abroad, Co-op, internships, pre-med, and flexibility during the upper-class years), the Sibley School faculty recommends that students delay use of advisor-approved (AA) electives until after the third semester. Students must seek advisor approval before taking an AA elective. Advanced placement credit may not count as an AA elective. Up to 6 credits of Reserve Officer Training Corps (ROTC) courses numbered 3000 or above or co-listed in an academic department are allowed as AA electives. Students must document AA electives approved before MAE affiliation within a month of registration as an MAE student. The faculty encourages students to consider the following as possible AA electives:

- an engineering distribution course
- courses stressing oral or written communications
- courses stressing the history of technology
- rigorous courses in the physical sciences (physics, biology, chemistry)
- courses in information science (mathematics, computer science)
- courses in methodologies (modeling, problem solving, synthesis, design)
- courses in technology (equipment, machinery, instruments, devices, processes)
- courses in business enterprise operations (e.g., economics, financial, legal)
- courses in organizational behavior
- courses in cognitive sciences

**Other considerations**

It is recommended that humanities, arts, and social sciences electives include studies in history of technology, societal impacts of technology, history, foreign languages, ethics, communications, political science, aesthetics, economics, and/or architecture.

The Sibley School encourages its students to spend a semester or year abroad at foreign universities with which the college has an exchange agreement, such as the Ecole Centrale Paris.

The technical-writing requirement of the common curriculum is satisfied by MAE 4272.

A limited set of second- and third-year courses is offered each summer under the auspices of the School of Continuing Education and Summer Sessions and the Engineering Cooperative Education Program.

**Preparation in Aerospace Engineering**

There is no separate undergraduate major in aerospace engineering, but students may prepare for a career or graduate program in this area by majoring in mechanical engineering and taking courses from the aerospace engineering minor or concentration, for example spacecraft engineering, introduction to aeronautics, and aerospace propulsion systems. It is also possible to prepare for a career or graduate program in aerospace engineering through appropriate course selection in other majors, for example: electrical and computer engineering, engineering physics, or the physical sciences. Subjects recommended as preparation for aerospace engineering endeavors include thermodynamics, fluid mechanics, structures, vibrations, feedback controls, applied mathematics, chemistry, and physics.

## OPERATIONS RESEARCH AND ENGINEERING

Offered by the School of Operations Research and Information Engineering

Contact: 203 Rhodes Hall, 255-5088, www.orie.cornell.edu

This major provides a broad education in the techniques and modeling concepts needed to design, analyze, and operate complex systems. The major prepares students for a wide range of careers including operations research, information engineering, entrepreneurship, operations management, consulting, financial engineering, financial services, and engineering management.

The foundation of the major is the development of basic skills in statistics, probability, mathematical optimization, and computer science. Required courses in manufacturing systems, cost accounting, and simulation build on these skills and provide engineering design experiences. In the senior year the curriculum is quite flexible. Students take ORIE electives to broaden and deepen their expertise in applied probability and statistics, industrial systems, optimization, information technology, financial engineering, and their applications.

Because of the wide range of career goals among OR&E students, and the large number of electives, students should consult with their major advisors to select electives that best meet their future goals.

Exceptional students interested in pursuing graduate studies are encouraged to speak with their faculty advisors concerning an accelerated program of study.

A student who intends to affiliate with the major in operations research and engineering should take ENGRD 2700 Basic Engineering Probability and Statistics after completing MATH 1920; MATH 2940 should be completed before or concurrently with ENGRD 2700. OR&E affiliates are required to complete MATH 1910, 1920, and 2940 (or their subject matter equivalents.) Either MATH 2930, CS 2800, or MATH 3040 may be used to satisfy the fourth-semester mathematics requirement. Students should discuss with their advisors which of these three courses is most appropriate to their future program of study in OR&E. The following considerations should be considered.

1. MATH 2930 (differential equations) is essential for advanced study in financial engineering. Also, MATH 2930 is a prerequisite for PHYS 2214, thus students who do not take MATH 2930 must plan to take CHEM 2080.
2. CS 2800 provides an introduction to discrete structures and algorithms of broad applicability in the field of operations research, particularly for fundamental models in the areas of optimization, production scheduling, inventory management, and information technology; it is also a prerequisite for certain upper-class Computer Science courses in the areas of information technology and algorithmic analysis.
3. MATH 3040 covers fundamentals of formal proof techniques; this material is recommended for students who intend to do advanced (Ph.D.-level) study in Operations Research or a related field.

Early consultation with a faculty member or the associate director for undergraduate studies may be helpful in making appropriate choices.

The required courses for the OR&E major and the typical terms in which they are taken are as follows:

| *Semester 2 or 3* | *Credits* |
|---|---|
| ENGRD 2110 Computers and Programming | 3 |
| ENGRD 2700 Basic Engineering Probability and Statistics | 3 |
| *Semester 4* | |
| ORIE 3120 Industrial Data and Systems Analysis* | 4 |
| *Semester 5* | |
| ORIE 3300 Optimization I | 4 |
| ORIE 3500 Engineering Probability and Statistics II | 4 |
| Behavioral Science (Organizational Behavior)† | 3 |
| Liberal elective | 3 |
| Advisor-approved elective | 3 |
| *Semester 6* | |
| ORIE 3150 Financial and Managerial Accounting (may be taken in semester 4) | 4 |
| ORIE 3310 Optimization II | 4 |
| ORIE 3510 Introductory Engineering Stochastic Processes I | 4 |
| Major-approved elective | 3 |
| Liberal elective | 3 |

*It is highly recommended that ORIE 3120 be taken in semester 4. If the student's schedule does not permit this, the course may be taken in semester 6 or 8.

†The behavioral science requirement can be satisfied by any of several courses, including the Johnson Graduate School of Management (JGSM) course NCC 5540 (offered only in the fall), which is recommended for those considering a graduate business degree, ILROB 1220, and 1750, HADM 1115, ENGRC 3350 (which also satisfies the technical writing requirement), and others.

The basic senior-year program, from which individualized programs are developed, consists of the following courses:

| | |
|---|---|
| ORIE 4580 Simulation Modeling and Analysis | 4 |
| Three upper-level ORIE electives as described below | 9 |
| Two major-approved electives (at least 3 credits must be outside ORIE) | 6 |
| Liberal electives | 6 |
| One advisor-approved elective | 3 |

Available ORIE electives are as follows:

Manufacturing and distribution systems: ORIE 4150, 4800, 4810, 4850, 5100, 5120, 5122, 5126 and JGSM NBA 6410

Optimization methods: ORIE 4154, 4300, 4320, 4330, 4350, 4360, and 4370

Applied probability and statistics: ORIE 4520, 4540, 4710 (2 credits), 4740, 4711 (2 credits), 4712 (2 credits), 5550, 5560, and 5770

Financial engineering: ORIE 4600, 4630, 5600, 5610, 5620, and 5640

### Academic Standing

Each student in the OR&E major should obtain a passing grade in every course; at least C– in ENGRD 2110 and 2700, ORIE 3120, 3150, 3300, 3310, 3500, 3510, and 4580; a GPA of 2.0 each semester; a GPA of 2.0 for OR&E major courses; and satisfactory progress toward completion of the degree requirements. Each student's performance is reviewed at the conclusion of each semester.

If at least C– is not earned in a required course, the course must be repeated within one year. The next course in a sequence (ORIE 3310 and 3510, in particular) may not be taken until a grade of C– or better is achieved in the prerequisite course. Failure to achieve at least C– in the second attempt will generally result in withdrawal from the major.

### Operations Research and Engineering Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Engineering Majors" as well as the following requirements.

The 9 additional credits of course work shall be from one or more of the following, with at least 4 credits in the first category:

1. Advanced courses in ORIE at the 5000 level or above.
2. A significant research experience or honors project under the direct supervision of an ORIE faculty member using ORIE 4999 ORIE Project. A significant written report must be submitted as part of this component.
3. A significant teaching experience under the direct supervision of a faculty member in ORIE using ORIE 4990 Teaching in ORIE.

#### Procedures

Each program must be approved by the associate director of undergraduate studies, and any changes to a program must be approved by the associate director.

## SCIENCE OF EARTH SYSTEMS

Offered by the Department of Earth and Atmospheric Sciences

Contact: 2124 Snee Hall, 255-5466, www.eas.cornell.edu

We live on a planet with finite resources and a finite capacity to recover quickly from human-induced environmental stresses. Natural hazards such as earthquakes, hurricanes, and volcanic eruptions can alter the course of history with little prior warning. As the human population grows, understanding the Earth and its resources becomes progressively more important to both future policymakers and ordinary citizens, who must find new sources of energy and sustain the quality of our environment. Because the human need to understand the Earth is so pervasive and the earth system is so multifaceted, the major covers the spectrum of modern earth sciences, including the structure, composition, and evolution of our planet; the planetary processes producing weather and climate; and processes on and near the earth's surface where the interactions of water, life, rock, and air produce our planetary environment.

The major is built on a rigorous introduction to this broad spectrum plus a concentration chosen by the student to obtain expertise in an area of interest and relevance to the student's career plans.

The major prepares students for a number of career paths including further graduate study in geology, geophysics, geochemistry, biogeochemistry, atmospheric sciences, ocean sciences, hydrology, or environmental sciences and engineering. Careers dealing with energy and mineral resources, natural hazards, weather and climate, ocean sciences, or environmental sciences are possible in academic research groups, governmental agencies, and the private sector. The major also prepares students for careers in environmental policy, law or medicine, science in the media, and K–12 science teaching.

### Requirements for the Major

This major has the same requirements as the Science of Earth Systems major in other Cornell undergraduate colleges. The major includes strong preparation in math, physics, chemistry, and biology. A second semester of chemistry (CHEM 2080 or CHEM 1570) is required with PHYS 2214 optional. Two semesters of biology are required (either BIOG 1101/1103–1102/1104 or BIOG 1109–1110). A second semester of biology can be replaced by CHEM 1570 if CHEM 2080 is also selected.

A required introductory course in earth science is satisfied by EAS 2200.

The core courses emphasize the interconnectedness of the Earth system, and are founded on the most modern views of the planet as an interactive and ever-changing system. Each crosses the traditional boundaries of disciplinary science. The major requires three of the following four core courses.

EAS 3010 Evolution of the Earth System

EAS 3030 Biogeochemistry

EAS 3040 Interior of the Earth

EAS 3050 Climate Dynamics

The concentration is achieved by completion of four intermediate to advanced-level courses (3000 level and up) that build on the core courses and have prerequisites in the required basic sciences and mathematics courses. Note that additional basic math and science courses may be required to complete the concentration courses, depending upon the student's choice of concentration. The concentration courses build depth and provide the student with a specific expertise in some facet of Earth system science. Four defined areas of specialization include geology, biogeochemistry, atmospheric sciences, and ocean sciences. Students may also design other concentrations. Examples include planetary science, ecological systems, geohydrology, and soil science. The concentration should be chosen during the junior year or before in consultation with the student's advisor and with approval of the Director of Undergraduate Studies. For concentrations beyond the four first named, approval by the SES Curriculum Committee is needed.

Exposure to the basic observations of earth science, whether directly in the out-of-doors, or indirectly by the many advanced techniques of remote sensing of our planet, or in the laboratory, is necessary to understand fully the chosen area of concentration in the major. Three credits of appropriate course work are required. Possibilities include the following:

Courses in the Hawaii Environmental Semester Program; or

Courses given by the Shoals Marine Laboratory; or

EAS 2500 Meteorological Observations and Instruments; or

EAS 3520 Synoptic Meteorology I; or

EAS 4170 Field Mapping in Argentina

EAS 4370 Geophysical Field Methods; or

EAS 4910 and/or EAS 4920 Undergraduate Research with appropriate choice of project; or

Field course or courses taught by another college or university (e.g. Semester at Sea).

Students should discuss with their faculty advisor whether the fourth core course listed above or the course used to fulfill the observation/field requirement may also be used to satisfy the concentration.

For more information contact Professor John Cisne, Department of Earth and Atmospheric Sciences, john.cisne@cornell.edu, or visit www.eas.cornell.edu.

#### Field Study in Hawaii

Field study is a fundamental aspect of earth system science. Students wishing to increase their field experience may fulfill some of the requirements for the Science of Earth Systems major by off-campus study through the Cornell Earth and Environmental Semester program (EES). The EES program, offered during the spring semester, emphasizes field-based education and research. It is based on the island of Hawaii, an outstanding natural laboratory for earth and environmental sciences. Courses that may be applied to the Science of Earth Systems major include EAS 3400, 3220, and 3510. The EES program also offers opportunities for internships with various academic, nonprofit, and government organizations. Typically, students participate in the EES program during their junior year, although exceptions are possible. For further information, see www.geo.cornell.edu/geology/classes/hawaii/.

### Science of Earth Systems Honors Program

The B.S. degree with honors is granted to engineering students who satisfy the requirements given at the beginning of the section "Engineering Majors" as well as the requirements of an honors thesis involving research (EAS 4910–4920 or 4990, 2 or more credits each) of breadth, depth, and quality. A written proposal of the honors project must be accepted by the student's advisor and the director of undergraduate studies early in the first semester of the student's senior year.

## ENGINEERING MINORS

Students may pursue minors in any department in any college that offers them, subject to limitations placed by the department offering the minor or by the students' major. Completed minors will appear on the student's transcript. Not all departments offer minors. Consult the appropriate section in *Courses of Study* or contact the appropriate department for information on minors offered and how to pursue a minor.

An engineering minor recognizes formal study of a particular subject area in engineering normally outside the major. Students undertaking a minor are expected to complete the requirements during the time of their continuous undergraduate enrollment at Cornell. Completing the requirements for an engineering minor (along with a major) may require more than the traditional eight semesters at Cornell. However, courses that fulfill minor requirements may also satisfy other degree requirements (e.g., distribution courses, advisor-approved, or major-approved electives), and completion within eight semesters is possible.

An engineering minor requires:

- successful completion of all requirements for an undergraduate degree.
- enrollment in a major that approves participation in the minor.
- satisfactory completion of six courses (at least 18 credits) in a college-approved minor.

Students may apply for certification of a minor at any time after the required course work has been completed in accordance with published standards. An official notation of certification of a minor appears on the Cornell transcript following graduation.

The College of Engineering offers minors in the following areas (offering units are indicated in parentheses):

Aerospace Engineering (MAE)

Applied Mathematics (TAM)

Biological Engineering (BEE)

Biomedical Engineering (BME)

Civil Infrastructure (CEE)

Computer Science (CS)

Electrical and Computer Engineering (ECE)

Engineering Management (CEE)

Engineering Statistics (ORIE)

Environmental Engineering (BEE/CEE)

Geological Sciences (EAS)

Game Design (CS)

Industrial Systems and Information Technology (ORIE)

Information Science (INFO)

Materials Science and Engineering (MSE)

Mechanical Engineering (MAE)

Operations Research and Management Science (ORIE)

Additional information on specific minors can be found below, in the *Engineering Undergraduate Handbook*, in the undergraduate major office of the department or school offering the minor, and in Engineering Advising.

## MINOR: AEROSPACE ENGINEERING

Offered by: Sibley School of Mechanical and Aerospace Engineering

Contact: 108 Upson Hall, 255-3573, www.mae.cornell.edu

Students intending to earn this minor should seek advice and pre-approval of their minor academic program from the associate director for undergraduate affairs in Mechanical Engineering before taking courses toward the minor.

The aerospace engineering minor develops the engineering analysis and design skills necessary for creating and understanding aerospace vehicles and their subsystems. The minor includes diverse topics relevant to applications both in the earth's atmosphere (e.g., aerodynamics) and in space (e.g., spacecraft thermal systems or orbital mechanics). Students in this minor will take at least four core aerospace courses, along with up to two supporting courses in engineering fundamentals or courses with applicability to aeronautics and spacecraft.

**Academic Standards:** A grade of at least C– in each course. If a course is offered only S–U, a grade of S is acceptable.

**Requirements:**

Six courses from the lists below, each worth at least 3 credits, must be completed. No substitutions will be accepted from other departments at Cornell or elsewhere.

**Rules for selecting courses:**

1. Rules for ME majors:
   a. Select least four courses from group A, of which you must choose MAE 3050 or MAE 3060 (or both).
   b. Select at most two courses from group B. No courses from group C may be used.
   c. Use at most four courses to satisfy both the Aerospace Minor requirements and the BSME degree requirements. The major concentration courses may not be among these overlapped courses.
2. Rules for other majors:
   a. Select least four courses from group A, of which you must choose MAE 3050 or MAE 3060 (or both).
   b. Select a total of at most two courses from group B and group C.
   c. Do not use any courses to satisfy requirements of both the Mechanical Engineering Minor and the Aerospace Engineering Minor.

Group A: Core Aerospace Engineering

MAE 3050 Intro to Aeronautics

MAE 3060 Spacecraft Engineering

MAE/ECE 4150 GPS: Theory and Design

*MAE 4291 Supervised Senior Design Experience, with Aerospace Focus or MAE 4900 Special Investigations in Mechanical and Aerospace Engineering, with Aerospace Focus

MAE 4230/5230 Intermediate Fluid Dynamics

MAE 5060 Aerospace Propulsion Systems

MAE 5070 Dynamics of Flight Vehicles

*MAE 4291 and 4900 require a form signed by the project advisor, stating that the project focuses on aerospace and is suitable as a core aerospace course for the minor. MAE 4291 or 4900 must be worth 3 credits or more. Students are restricted to at most one MAE 4291 OR one MAE 4900 counting toward the minor (may not count both MAE 4291 and MAE 4900 toward the minor).

Group B: Courses Applicable to Aerospace Engineering

MAE 4170/5170 Introduction to Robotics: Dynamics, Control, Design

MAE 4550/CEE 4770/MSE 5550/TAM 4550 Introduction to Composite Materials

MAE 4700/5700 Finite Element Analysis for Mechanical and Aerospace Design or CEE 4720 Introduction to the Finite Element Method

MAE 4770/5770 Engineering Vibrations

MAE 4780/5780/CHEME 4720/ECE 4720 Feedback Control Systems

MAE 5430 Combustion Processes

MAE 5710 Applied Dynamics or TAM 5700 Intermediate Dynamics

Group C: Fundamentals

ENGRD 2020

ENGRD 2030

MAE 2120

ENGRD/MAE 2210

MAE 3230

MAE 3240

MAE 3250

MAE 3260

MAE 3780 or ECE 2100/ENGRD 2100 or PHYS 3360

# MINOR: APPLIED MATHEMATICS

Offered by the Department of Theoretical and Applied Mechanics

Contact: Richard Rand, 207 Kimball Hall, 255-7145, rhr2@cornell.edu, www.tam.cornell.edu/Undergrad.html

All undergraduates are eligible to participate in this minor.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses beyond MATH 2940, to be chosen as follows:

a. At most one course from any one of the groups 1, 2, 3, or 4.
b. At least three courses from groups 5 and 6.
c. At most one 2000-level course.
d. At most one course that is offered by the student's major department.

1. Analysis

AEP 3210 Mathematical Physics I

MATH 3210 Manifolds and Differential Forms

MATH 4200 Differential Equations and Dynamical Systems

TAM 3100 Introduction to Applied Mathematics I

2. Computational Methods

CS 4210 Numerical Analysis

ENGRD 3220 Introduction to Scientific Computation

ENGRD 3200 Engineering Computation

ORIE 3300 Optimization I

3. Probability and Statistics

CEE 3040 Uncertainty Analysis in Engineering

ECE 3100 Introduction to Probability and Random Signals

ENGRD 2700 Basic Engineering Probability and Statistics

MATH 4710 Basic Probability

ORIE 3500 Engineering Probability and Statistics II

4. Applications

AEP 3330 Mechanics of Particles and Solid Bodies

CEE 3310 Fluid Mechanics

CEE 3710 Modeling of Structural Systems

CHEME 3230 Fluid Mechanics

CS 2800 Discrete Structures

CS 2850 Networks

ECE 3200 Networks and Systems

ECE 4250 Digital Signal Processing

MAE 3230 Introductory Fluid Mechanics

MSE 3030 Thermodynamics of Condensed Systems

5. Advanced courses

Only one of these three may be chosen:

AEP 3220 Mathematical Physics II

MATH 4220 Applied Complex Analysis

TAM 3110 Introduction to Applied Mathematics II

Only one of the following two may be chosen:

ECE 4110 Random Signals in Communications and Signal Processing

ORIE 3510 Introductory Engineering Stochastic Processes I

Only one of the following two may be chosen:

MAE 5710 Applied Dynamics

TAM 5700 Intermediate Dynamics

Also, you may choose from:

CS 3810 Introduction to Theory of Computing

CS 4510 Introduction to Computational Biophysics

CS 4820 Introduction to the Analysis of Algorithms

ORIE 3310 Optimization II

ORIE 4330 Discrete Models

ORIE 4350 Introduction to Game Theory

ORIE 4520 Introductory Engineering Stochastic Processes II

ORIE 5600 Financial Engineering with Stochastic Calculus I

ORIE 5610 Financial Engineering with Stochastic Calculus II

TAM 5780 Nonlinear Dynamics and Chaos

TAM 6100 Methods of Applied Mathematics I

TAM 6110 Methods of Applied Mathematics II

6. Mathematics courses

Any 3000+ level course offered by the Mathematics Department in algebra, analysis, probability/statistics, geometry, or logic, with the following exceptions:

a. MATH 3230 or 4200, if any course from group 1 is chosen
b. MATH 4710, if any course from group 3 is chosen
c. MATH 4220, if TAM 3110 or AEP 3220 is chosen from group 5
d. Only one of the following may be chosen:

MATH 3320 Algebra and Number Theory

MATH 3360 Applicable Algebra

# MINOR: BIOLOGICAL ENGINEERING

Offered by the Department of Biological and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255-2173, www.bee.cornell.edu

Students in all majors except biological engineering may participate. Students should meet with the BE coordinator as soon as they decide to pursue the minor and before their senior year. They will work with a BEE faculty advisor, who will assist them in completing their minor.

**Educational objectives of the minor:**

Biological engineering is the application of engineering to living systems. Examples of engineering efforts in this field include the development of new biosensor technologies, study and control of biologically based matter transformation systems, and development of engineered devices to study and regulate fundamental biological processes. The biological engineering minor is an opportunity for students to further their understanding of living systems and to increase their knowledge of the basic transport processes that occur within these systems. Courses in the minor provide opportunities to analyze and manipulate living systems at the molecular, cellular, and system levels.

**Academic standards:** At least C– in each course in the minor and a GPA ≥ 2.0 in all courses in the minor

**Requirements**

At least six courses (≥ 18 credits), with at least three courses and 9 credits taught in BEE as follows:

BEE 3500 Biological and Environmental Transport Processes (3 credits): required

I. **Biology Foundation** (at least one but no more than two courses)

- BIOBM 3300 or 3310–3320 Biochemistry
- BIOMI 2900 Microbiology
- BIONB 2220 Neurobiology

II. **Biological Engineering Core** (at least one but no more than two courses)

- BEE 2600 Principles of Biological Engineering
- BEE 3500 Biological and Environmental Transport Processes
- BEE 3600 Molecular and Cellular Bioengineering
- BEE 3310 Bio-fluid Mechanics

III. **Biological Engineering Concentration Electives** (minimum of 3 courses)

Choose any three courses from the concentration lists below. Courses appearing in more than one concentration do not double count. BEE 3600 may be taken as either a concentration elective or a core course.

**Biomedical Engineering Concentration**

- AEP 4700 Biophysical Methods (also BIONB 4700)
- BEE 3600 Molecular and Cellular Bioengineering (also BME 3600)
- BEE 3650 Properties of Biological Materials
- BEE 4500 Bioinstrumentation
- BEE 4530 Computer-Aided Engineering: Applications to Biomedical Processes (also MAE 4530)
- BEE 4540 Physiological Engineering
- BEE 4590 Biosensors and Bioanalytical Techniques
- BME 3300 Introduction to Computational Neurosciences (also BIONB/PSYCH/COGST 3300)
- BME 4040 Biomedical System Design (also ECE 4020)
- BME 5390 Biomedical Materials and Devices for Human Body Repair (also FSAD 4390)
- BME 5650 Biomechanical Systems—Analysis and Design (also MAE 5650)
- CHEME 4810 Biomedical Engineering (also BME 4810)
- ECE 5780 Computer Analysis of Biomedical Images
- MAE 4630 Neuromuscular Biomechanics (also BME 4630)
- MAE 4640 Orthopaedic Tissue Mechanics
- MSE 4610 Biomedical Materials and Their Applications

**Bioprocess Engineering Concentration**

- BEE 3600 Molecular and Cellular Bioengineering (also BME 3600)
- BEE 4500 Bioinstrumentation
- BEE 4530 Computer Aided Engineering: Applications to Biomedical Processes (also MAE 4530)
- BEE 4590 Biosensors and Bioanalytical Techniques
- BEE 4640 Bioseparation Processes
- BEE 4840 Metabolic Engineering
- CHEM 3000 Quantitative Chemistry (does not count for Engineering credit)
- CHEME 3320 Analysis of Separation Processes
- CHEME 5430 Biomolecular Engineering of Bioporocesses

**Bioenvironmental Engineering Concentration**

- BEE 3710 Physical Hydrology for Ecosystems
- BEE 4350 Principles of Aquaculture
- BEE 4710 Introduction to Groundwater (also EAS 4710)
- BEE 4730 Watershed Engineering
- BEE 4780 Ecological Engineering
- BEE 6510 Bioremediation Engineering Organisms to Clean up the Environment
- CEE 4510 Microbiology for Environmental Engineering
- CEE 4520 Water Supply Engineering

# MINOR: BIOMEDICAL ENGINEERING

Offered by the Department of Biomedical Engineering (BME)

Contact: Carol Casler, 120 Olin Hall, 255-1489, www.bme.cornell.edu/academics/undergraduate/biomedminor.cfm

All undergraduates in any college are eligible to participate in this minor. Students may participate in only one of these areas of interest: the biological engineering minor or the biomedical engineering minor.

Educational Objectives: Biomedical engineering is the application of engineering principles and methods to a wide array of problems associated with human health. The discipline includes the design of biocompatible materials, prostheses, surgical implants, artificial organs, controlled drug-delivery systems, and wound closure devices. Diagnosing diseases and determining their biological origins depend upon increasingly sophisticated instrumentation and the use of mathematical models. This minor allows students to gain exposure to the breadth and depth of biomedical engineering offerings at Cornell, to prepare for advanced studies in biomedical engineering, and to obtain transcript recognition for their interest and capability in this rapidly growing area.

Students are asked to complete a form declaring their interest in the minor with the biomedical engineering undergraduate minor coordinator in 120 Olin Hall. On the form you will be asked to choose a BME faculty advisor that you can consult about the BME minor plan.

**Academic standards:** At least C– in each course in the minor. A cumulative GPA ≥ 2.0 for all courses in the minor.

**Requirements**

The 1-credit Bioengineering Seminar as well as at least six courses (≥ 18 credits) from the five categories listed below; two courses need to be in categories 1. Introductory biology and/or 2. Advanced biology with no more than one course from category 1. Four courses must come from the following categories: 3. Molecular and cellular biological engineering, 4. Biomedical engineering analysis of physiological systems, and 5. Biomedical engineering applications with courses from at least two of these categories represented. At least four of the six courses must not be specifically required major degree courses or cross-listings.

*Required course*: BEE/BME 5010 Bioengineering Seminar (1 credit, 1 semester)

**Category 1. Introductory biology (maximum of 4 credits and one course grouping toward the BME minor)**

- A score of 5 on (CEEB) Advanced Placement Biology
- A score of 4 on (CEEB) Advanced Placement Biology and ENGRI 1310: Introduction to Biomedical Engineering
- A score of 4 on (CEEB) Advanced Placement Biology and BIOG 1103 or BIOG 1104 Biological Sciences, Laboratory
- BIOG 1101, 1102, 1103, and 1104 Biological Sciences
- BIOG 1105 and 1106 Introductory Biology
- BIOG 1107 and 1108 General Biology

BIOG 1110 Biological Principles and ENGRI 1310 Introduction to Biomedical Engineering

**Category 2. Advanced biology**

BIOAP 3110/VTBMS 3460 Introductory Animal Physiology Lectures

BIOBM 3300 Principles of Biochemistry, Individualized Instruction

BIOBM 3310 Principles of Biochemistry, Proteins and Metabolism

BIOBM 3320 Principles of Biochemistry, Molecular Biology

BIOBM 3330 Principles of Biochemistry, Proteins, Metabolism, and Molecular Biology

BIOGD 2810 Genetics

BIONB 2220 Neurobiology and Behavior II: Introduction to Neurobiology

BIOMI 2900 General Microbiology Lectures

**Category 3. Molecular and cellular biomedical engineering**

AEP 2520/ENGRD 2520 The Physics of Life

BEE 3600/BME 3600 Molecular and Cellular Bioengineering

BME 3010/CHEME 4010* Molecular Principles of Biomedical Engineering

BME 3020/CHEME 4020* Cellular Principles of Biomedical Engineering

**Category 4. BME analysis of physiological systems**

BEE 4540 Physiological Engineering

BIONB 3300/BME 3300/COGST 3300/ PSYCH 3300 Introduction to Computational Neuroscience

BIONB 4910/BME 4910 Principles of Neurophysiology

BME 4010/MAE 4660* Biomedical Engineering of Metabolic and Structural Systems

BME 4020* Electrical and Chemical Physiology

CHEME 4810/BME 4810 Biomedical Engineering

MAE 4640/BME 4640 Orthopaedic Tissue Mechanics

**Category 5. Biomedical engineering applications**

AEP 4700/BIONB 4700/BME 5700 Biophysical Methods

BEE 3650 Properties of Biological Materials

BEE 4500 Bioinstrumentation

BEE 4530/MAE 4530 Computer-Aided Engineering: Applications to Biomedical Processes

BEE 4590 Biosensors and Bioanalytical Techniques

BME 4110 Science and Technology Approaches to Problems in Human Health

BME 5810/MAE 5680 Soft Tissue Biomechanics

CS 3510/BIOBM 3510/ENGRD 3510 Numerical Methods in Computational Molecular Biology

ECE 5020/BME 5020 Biomedical System Design

ECE 5780 Computer Analysis of Biomedical Images

MSE 4610 Biological Materials and Their Applications

MSE 5620/BME 5620 Biomineralization: The Formation and Properties of Inorganic Biomaterials

FSAD 4390/BME 5390 Biomedical Materials and Devices for Human Body Repair

*Students interested in professional practice as biomedical engineers should consider an M.Eng. degree in BME. The recommended sequence for admission is as follows: two courses from categories 1 and 2, BME 3010, 3020, 4010, and 4020. The program requires students to have a knowledge of molecular and cellular biomedical engineering, and of biomedical engineering analysis of physiological systems.

## MINOR: CIVIL INFRASTRUCTURE

Offered by the School of Civil and Environmental Engineering

Contact: 221 Hollister Hall, 255-3412, www.cee.cornell.edu

Students affiliated with all majors except civil engineering may participate in this minor.

The minor in civil infrastructure is intended to introduce undergraduates to the engineering methodologies of mechanics, materials, analysis, design, and construction and to show how these are used in solving problems in the development, maintenance, and operation of the built environment that is vital for any modern economy.

**Academic standards:** At least C in each course in the minor

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. Required course: ENGRD 2020 Mechanics of Solids
2. Additional courses: choose any five (groupings are for information only)*

**Geotechnical engineering**

CEE 3410 Introduction to Geotechnical Engineering

CEE 4400 Foundation Engineering

CEE 4410 Retaining Structures and Slopes

CEE 4440 Environmental Site and Remediation Engineering

**Structural engineering**

CEE 3710 Structural Modeling and Behavior

CEE 3720 Intermediate Solid Mechanics

CEE 4710 Fundamentals of Structural Mechanics

CEE 4720 Introduction to the Finite Element Method

CEE 4730 Design of Concrete Structures

CEE 4740 Design of Steel Structures

CEE 4780 Structural Dynamics and Earthquake Engineering

**Other related courses**

CEE 5950 Construction Planning and Operations

*Other CEE courses may be approved by petition in advance

## MINOR: COMPUTER SCIENCE

Offered by the Department of Computer Science

Contact: 303 Upson Hall, 255-0982, www.cs.cornell.edu

Students affiliated with all majors except Computer Science are eligible to participate in this minor. This minor is for students who anticipate that computer science will play a prominent role in their academic and professional career.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses (18 credits) chosen as follows:

1. Required courses

   CS/ENGRD 2110 Computers and Programming

   One of the following:

   CS/ENGRD 3220 Introduction to Scientific Computing,

   CS 4210 Numerical Analysis and Differential Equations, or

   CS 4220 Numerical Analysis: Linear and Nonlinear Equations

   One of the following:

   CS 3410 Systems Programming, or

   CS 3420/ECE 3120 Computer Organization

2. Additional courses

   Three CS courses numbered 3000 or higher with the following exceptions:

   CS 4999 and seminars are excluded

   CS 2800 is allowed

Cross-listed courses cannot be applied to the minor unless taken under the CS rubric, with the sole exception of ECE 3140. All qualifying courses must be taken at Cornell for a letter grade. No substitutions allowed.

## MINOR: ELECTRICAL AND COMPUTER ENGINEERING

Offered by the School of Electrical and Computer Engineering

Contact: 223 Phillips Hall, 255-4309, www.ece.cornell.edu

Students affiliated with all majors except Electrical and Computer Engineering are eligible to participate in this minor, but MSE students must receive prior written approval from both MSE and ECE, via petition.

This minor offers the opportunity to study analog and digital circuits, signals and systems, and electromagnetics and to concentrate at higher levels in one of several different areas such as circuit design, electronic devices, communications, computer engineering, networks, and space engineering.

**Academic standards:** At least C– in each course in the minor. GPA ≥ 2.3 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. Two of the following:

   ECE/ENGRD 2100 Introduction to Circuits for Electrical and Computer Engineers

   ECE 2200 Signals and Information

   ECE/ENGRD 2300 Introduction to Digital Logic Design

2. Two of the following:

   ECE 3030 Electromagnetic Fields and Waves

   ECE 3100 Introduction to Probability and Random Signals

   ECE 3140/CS 3420 Computer Organization or CS 3410 Systems Programming

   ECE 3150 Introduction to Microelectronics

3. One other ECE course at the 3000 level or above (3-credit minimum)

4. One other ECE course at the 4000 level or above (3-credit minimum)

## MINOR: ENGINEERING MANAGEMENT

Offered by the School of Civil and Environmental Engineering

Contact: 221 Hollister Hall, 255-3412, www.cee.cornell.edu

Students affiliated with all majors are eligible to participate in this minor. CEE students may not use courses simultaneously to satisfy a requirement for the minor and as a major-approved elective or design elective. ORE students have some specific restrictions and requirements as noted below.

This minor focuses on giving students a basic understanding of engineering economics, accounting, statistics, project management methods, and analysis tools necessary to manage technical operations and projects effectively. The minor provides an important set of collateral skills for students in any engineering discipline.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. Required courses (3):

   CEE 3230 Engineering Economics and Management

   or ORIE 4150 Economic Analysis of Engineering Systems

   ORIE 3150 Financial and Managerial Accounting[1]

   CEE 3040 Uncertainty Analysis in Engineering[2]

   or ENGRD 2700 Basic Engineering Probability and Statistics

   or ECE 3100 Introduction to Probability and Random Signals

2. Additional courses—choose any three[3]

   CEE 4060 Civil Infrastructure Systems

   CEE 4920 Engineers for a Sustainable World: Engineering in International Development

   CEE 5930 Engineering Management Methods[4]

   CEE 5940 Economic Methods for Engineering Management

   CEE 5950 Construction Planning and Operations

   CEE 5960 Management Issues in Forensic Engineering

   CEE 5970 Risk Analysis and Management

   CEE 5980 Introduction to Decision Analysis

   NBA 5070 Entrepreneurship for Scientists and Engineers

   or MAE/ENGRG 4610/ORIE 4152 Entrepreneurship for Engineers

   or BEE 4890 Engineering Entrepreneurship, Management and Ethics

[1]ORIE students must substitute NCC 5560 or NBA 5000 for ORIE 3500

[2]TAM 3100 cannot be substituted for CEE 3040

[3]Other courses approved by petition in advance

[4]This course is not accepted for ORIE students

## MINOR: ENGINEERING STATISTICS

Offered by the School of Operations Research and Information Engineering

Contact: 203 Rhodes Hall, 255-5088, www.orie.cornell.edu

Students affiliated with all majors except Operations Research and Engineering are eligible to participate in this minor.

The goal of the minor is to provide the student with a firm understanding of statistical principles and engineering applications and the ability to apply this knowledge in real-world situations.

**Academic standards:** At least C– in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. Required courses:

   ENGRD 2700 Basic Engineering Probability and Statistics

   ORIE 3500 Basic Engineering Probability and Statistics II *or* ECE 3100 Introduction to Probability and Random Signals

2. Four of these (≥ 11 credits)*:

   ORIE 3510 Introductory Engineering Stochastic Processes I *or* ECE 4110 Random Signals in Communications/Signal Processing

   ORIE 4580 Simulation Modeling and Analysis

   ORIE 4710 Applied Linear Statistical Models

   ORIE 4711 Experimental Design

   ORIE 4712 Regression

   ORIE 5550 Applied Time Series Analysis

   ORIE 5770 Quality Control

   MATH 4720 Basic Probability *or* BTRY 4090 Theory of Statistics

   BTRY 6020 Statistical Methods II

   BTRY 6030 Statistical Methods III *or* ILRST 4110 Statistical Analysis of Qualitative Data

   ILRST 3100 Statistical Sampling

   ILRST 4100 Techniques of Multivariate Analysis

*Other course options approved by petition in advance. Some of these courses require others as prerequisites. All these courses are cross-listed under the Department of Statistical Science.

## MINOR: ENVIRONMENTAL ENGINEERING

Offered jointly by the Department of Biological and Environmental Engineering and the School of Civil and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255-2173, www.bee.cornell.edu, or 221 Hollister Hall, 255-3412, www.cee.cornell.edu

Students affiliated with all majors except environmental engineering are eligible to participate in this minor. Students majoring in biological engineering or civil engineering are eligible if they are not following the environmental concentration offered by those majors. Eligible civil engineering majors may not use courses simultaneously to satisfy a requirement for the minor and as a major-approved elective or design elective.

A fundamental challenge for the engineering profession is development of a sustainable society and environmentally responsible industry and agriculture reflecting an integration of economic and environmental objectives. We are called upon to be trustees and managers of our nation's resources, the air in our cities, and water in our aquifers, streams, estuaries, and coastal areas. This minor encourages engineering students to learn about the scientific, engineering, and economic foundations of environmental engineering so that they are better able to address environmental management issues.

**Academic standards:** At least C– in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen from the following groups, with at least one course from each group.

**Group A. Environmental engineering processes:**

BEE/ENGRD 2510 Engineering for a Sustainable Society

CEE 3510 Environmental Quality Engineering

CEE 4510 Microbiology for Environmental Engineering

CEE 4520 Water Supply Engineering

CEE 4530 Laboratory Research in Environmental Engineering

CEE 4540 Sustainable Small-Scale Water Supplies

CEE 4550 AguaClara: Sustainable Water Supply Project

BEE 4760 Solid Waste Engineering

BEE 4780 Ecological Engineering

CEE 4440 Environmental Site and Remediation Engineering

BEE/EAS 4800 Introduction to Atmospheric Chemistry

CEE 4920 Engineers for a Sustainable World

BEE 6510 Bioremediation

CEE 6530 Water Chemistry for Environmental Engineering

CEE 6560 Physical/Chemical Process

CEE 6570 Biological Processes

CEE 6580 Biodegradation and Biocatalysis

**Group B. Environmental systems**

ENGRI/CEE 1130* Water Treatment Design (*may count only if taken before the junior year)

BEE 4750 Environmental Systems Analysis

CEE 5970 Risk Analysis and Management

CEE 6230 Environmental Quality Systems Engineering

**Group C. Hydraulics, hydrology, and environmental fluid mechanics**

CEE 3310 Fluid Mechanics (CHEME 3230 or MAE 3230 may be substituted for CEE 3310)

CEE 3320 Hydraulic Engineering

BEE 3710 Physical Hydrology for Ecosystems

BEE 4710 Introduction to Groundwater

CEE 4320 Hydrology

CEE 4360 Case Studies in Environmental Fluid Mechanics

CEE 4370 Experimental Methods in Fluid Dynamics

BEE 4730 Watershed Engineering

BEE 4740 Water and Landscape Engineering Applications

CEE 6310 Computational Simulation of Transport in the Environment

CEE 6330 Flow in Porous Media and Groundwater

CEE 6550 Transport, Mixing, and Transformation in the Environment

BEE 6710 Analysis of the Flow of Water and Chemicals in Soils

BEE 6720 Drainage

## MINOR: GAME DESIGN

Offered by the Department of Computer Science

See: gdiac.cis.cornell.edu/courses.php

Requirements:

At least six (6) courses (18-credit minimum) chosen as follows:

Required courses: Complete the following two courses:

- CIS 3000 Introduction to Computer Game Design
- CIS 4002 Advanced Projects in Game Design

Additional Courses: Choose four of the following 12 courses:

CS-focused courses:

- CS/ENGRD 2110 Object-Oriented Programming and Data Structures
- CS 4450 Computer Networks
- ARCH 3704/CS 4620 Introduction to Computer Graphics
- CS 4700 Foundations of Artificial Intelligence
- CS 5620 Interactive Computer Graphics
- CS 5643 Physically Based Animation for Computer Graphics

Other courses:

- ART 2730/CIS 5640 (CS 5640 not allowed) Advanced Animation
- COMM 4220 Psychology of Entertainment Media
- ECE 4760 Designing with Microcontrollers
- COMM/INFO 3450 Human-Computer Interaction
- COMM/INFO 4400 Advanced Human-Computer Interaction Design
- COGST 3420/PSYCH 3420/VISST 3422 Human Perception: Applications to Computer Graphics, Art, and Visual Display

Academic Standards

At least a letter grade of C is required for each course in the minor

Note: CS majors cannot take courses from the CS-focused list for the Game Design minor.

## MINOR: INDUSTRIAL SYSTEMS AND INFORMATION TECHNOLOGY

Offered by the School of Operations Research and Information Engineering

Contact: 203 Rhodes Hall, 255-5088, www.orie.cornell.edu

Students affiliated with all majors except Operations Research and Engineering and Information Science, Systems, and Technology are eligible to participate in this minor.

The aim of this minor is to provide an in-depth education in issues central to the design and analysis of operational systems, and the tools from information technology that have become an integral part of the manufacturing, finance, service, and public health industries. Students will become familiar with the problems, perspectives, and methods found in these fields and be prepared to work with professionals in designing and managing them. That is, rather than providing a comprehensive view of the range of methodological foundations of operations research, this minor is designed to give the student a focused education in application areas closely associated with these techniques.

**Academic standards:** At least C– in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. Required courses:

   ENGRD 2700 Basic Engineering Probability and Statistics

   ORIE 3120 Industrial Data and Systems Analysis

   ORIE 4800 Information Technology

2. The remaining courses chosen from:

   ORIE 3150 Financial and Managerial Accounting

   ORIE 3300 Optimization I

   ORIE 4150 Economic Analysis of Engineering Systems

   ORIE 4580 Simulation Modeling and Analysis

   ORIE 4810 Delivering OR Solutions with Information Technology

   ORIE 4850 Applications of Operations Research and Game Theory to Information Technology

   ORIE 5100 Design of Manufacturing Systems

   ORIE 5120 Production Planning and Scheduling Theory and Practice

   ORIE 5770 Quality Control

## MINOR: INFORMATION SCIENCE

Offered by the Department of Computer Science

Contact: Undergraduate Programs Office, 303 Upson Hall, 255-9837, www.infosci.cornell.edu

Students affiliated with any major except Information Science, Systems, and Technology are eligible to participate in this minor.

The interdisciplinary field of information science covers all aspects of digital information. The program has three main areas: information systems, human-centered systems, and social systems. Information systems studies the computer science problems of representing, storing, manipulating, and using digital information. Human-centered systems studies the relationship between humans and information, drawing from human-computer interaction and cognitive science. Social systems examines information in its economic, legal, political, cultural, and social contexts.

The minor has been designed to ensure that students have substantial grounding in all three areas in addition to having a working knowledge of basic probability and statistics necessary for analyzing real-world data.

**Academic standards:** At least C in all courses for the minor; S–U courses are not allowed.

**Requirements**

Note: These requirements apply to students in the College of Engineering. Students who are not in the College of Engineering should refer to the IS minor requirements listed in the CIS section of this publication.

At least six courses (18 credits) chosen as follows:

- Statistics: one course (must be ENGRD 2700 or CEE 3040)
- Information Systems: two courses
- Human-Centered Systems: one course
- Social Systems: one course
- Elective: one additional course from either Human-Centered Systems or Social Systems

**Statistics**

An introductory course that provides a working knowledge of basic probability and statistics and their application to analyzing real-world data.

ENGRD 2700 Basic Engineering Probability and Statistics

CEE 3040 Uncertainty Analysis in Engineering

**Information Systems**

INFO 1700 Computation, Information, and Intelligence

CS 2110 Object-Oriented Programming and Data Structures*

INFO 2300 Intermediate Design and Programming for the Web*

CIS 3000 Introduction to Computer Game Design

INFO 3300 Data-Driven Web Applications

LING 4424 Computational Linguistics

INFO 4300 Information Retrieval

INFO 4302 Web Information Systems

CS 4320 Introduction to Database Systems

CS 4620 Introduction to Computer Graphics

CS 4700 Foundations of Artificial Intelligence

LING 4474 Introduction to Natural Language Processing

ORIE 4740 Statistical Data Mining I

CS 4780 Machine Learning

ORIE 4800 Information Technology

ORIE 4810 Delivering OR Solutions with Information Technology

ORIE 4850 Applications of Operations Research and Game Theory to Information Technology

CS 5150 Software Engineering

CS 5430 System Security

INFO 5300 Architecture of Large-Scale Information Systems

ECE 5620 Fundamental Information Theory

CS 5780 Empirical Methods in Machine Learning and Data Mining

*Computer Science majors may not use INFO 2300. CS 2110 cannot be used by majors for which it is a required course, e.g., Computer Science (CS) and Operations Research and Information Engineering (ORIE).

**Human-centered systems**

COGST 1101 Introduction to Cognitive Science

PSYCH 2050 Perception

INFO 2140 Cognitive Psychology

INFO 2450 Psychology of Social Computing

PSYCH 2800 Introduction to Social Psychology

PSYCH 3420 Human Perception: Applications to Computer Graphics, Art, and Visual Display

INFO 3450 Human–Computer Interaction Design

PSYCH 3470 Psychology of Visual Communications

INFO 3650 Technology in Collaboration

PSYCH 3800 Social Cognition

PSYCH 4130 Information Processing: Conscious and Unconscious

PSYCH 4160 Modeling Perception and Cognition

INFO 4400 Advanced Human-Computer Interaction Design

INFO 4450 Seminar in Computer-Mediated Communication

INFO 4500 Language and Technology

DEA 4700 Applied Ergonomic Methods

**Social systems**

INFO 2040 Networks

STS 2501 Technology in Society

INFO 2921 Inventing an Information Society

ECON 3010 Microeconomics*

SOC 3040 Social Networks and Social Processes

ECON 3130 Intermediate Microeconomic Theory*

INFO 3200 New Media and Society

AEM 3220 Technology, Information, and Business Strategy*

INFO 3490 Media Technologies

INFO 3551 Computers: From the 17th Century to the Dotcom Boom

INFO 3561 Computing Cultures

INFO 3660 History and Theory of Digital Art

ECON 3680 Game Theory*

INFO 3871 The Automatic Lifestyle: Consumer Culture and Technology

STS 4111 Knowledge, Technology, and Property

ECON 4190 Economic Decisions Under Uncertainty

COMM 4280 Communication Law

INFO 4290 Copyright in the Digital Age

ORIE 4350 Introduction to Game Theory*

INFO 4144 Responsive Environments

INFO 4470 Social and Economic Data

INFO 8848 Computational Methods for Complex Networks

HADM 5574 Strategic Information Systems*

ECON 4760/4770 Decision Theory I and II

HADM 4489 The Law of the Internet and E-Commerce

INFO 5150 Culture, Law, and Politics of the Internet

*Only one of ECON 3010 and 3130 may be taken for IS credit. Only one of ORIE 4350 and ECON 3680 may be taken for IS credit. Only one of AEM 3220 and HADM 5574 may be taken for IS credit.

## MINOR: MATERIALS SCIENCE AND ENGINEERING

Offered by the Department of Materials Science and Engineering

Contact: 214 Bard Hall, 255-9159, www.mse.cornell.edu

Students affiliated with all majors except materials science and engineering are eligible to participate in this minor.

Materials properties are the foundation of many engineering disciplines including mechanical, civil, chemical, and electrical engineering. This minor provides students with a fundamental understanding of mechanisms that determine the ultimate performance, properties, and processing characteristics of modern materials.

**Academic standards:** At least C in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. ENGRD 2610 Mechanical Properties of Materials: From Nanodevices to Superstructures, or ENGRD 2620 Electronic Materials for the Information Age
2. Two of:

   MSE 2060 Atomic and Molecular Structure of Matter

   MSE 3010 Materials Chemistry

   MSE 3030 Thermodynamics of Condensed Systems

   MSE 3040 Kinetics, Diffusion, and Phase Transformations

   MSE 3050 Electronic, Magnetic, and Dielectric Properties of Materials

   MSE 4020 Mechanical Properties of Materials, Processing, and Design
3. Three electives chosen from:

   Any MSE course at the 3000 level or above.

Selected courses in materials properties and processing (at the 3000 level or above) from AEP, CHEME, CEE, ECE, MAE, PHYS, and CHEM, as approved by the MSE undergraduate major coordinator.

## MINOR: MECHANICAL ENGINEERING

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 108 Upson Hall, 255-3573, www.mae.cornell.edu

Students affiliated with all majors except MAE are eligible to participate in this minor. Students intending to earn this minor should seek advice and pre-approval of their minor academic program from the associate director for undergraduate affairs in mechanical engineering before taking courses toward the minor.

**Academic standards:** At least C– in each course in the minor.

**Requirements**

At least six courses (≥ 18 credits) from among the following: MAE courses at the 2000 level or above; ENGRD 2020 Mechanics of Solids; ENGRD 2030 Dynamics.

Rules for selecting courses:

1. The selection of courses must satisfy the following three requirements.
   a. At least two courses must be numbered above 3000.
   b. At least one course must be either (i) numbered above 5000 or (ii) numbered above 3260 and have as a prerequisite ENGRD 2020, 2030, or a MAE course.
   c. Each course must be worth at least 3 credits.
2. All courses used to satisfy the MAE minor must be MAE courses, ENGRD 2020 or 2030. No substitutions will be accepted from other departments at Cornell or elsewhere. Transfer credit may not be used to satisfy the MAE minor. MAE 1110 Naval Ship Systems, or MAE 4980 Teaching Experience in Mechanical Engineering, may not be used toward satisfying the M.E. minor.

## MINOR: OPERATIONS RESEARCH AND MANAGEMENT SCIENCE

Offered by the School of Operations Research and Information Engineering

Contact: 203 Rhodes Hall, 255-5088, www.orie.cornell.edu

Students affiliated with all majors except Operations Research and Engineering and Information Science, Systems, and Technology are eligible to participate in this minor.

Operations research and management science supports decision making through modeling and analysis of complex systems. This understanding is used to predict system behavior and improve system performance. This minor gives the student the opportunity to obtain a wide exposure to the core methodological tools of operations research and management science, including mathematical programming, stochastic and statistical models, and simulation. The intent of this minor is to provide a broad knowledge of the fundamentals, rather than to train the student in a particular application domain. With this preparation, students can adjust their advanced courses and pursue either methodological or application-oriented areas most relevant to their educational goals.

**Academic standards:** At least C– in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. At least three of these courses:

   ENGRD 2700 Basic Engineering Probability and Statistics

   ORIE 3300 Optimization I

   ORIE 3310 Optimization II

   ORIE 3500 Engineering Probability and Statistics II

   ORIE 3510 Introduction to Engineering Stochastic Processes I

   ORIE 4580 Simulation Modeling and Analysis
2. Any ORIE courses at the 3000 level or higher (including those in 1).

## MINOR: SCIENCE OF EARTH SYSTEMS

Offered by the Department of Earth and Atmospheric Sciences

Contact: 2124 Snee Hall, 255-5466, www.eas.cornell.edu

Students affiliated with all majors except science of earth systems are eligible to participate.

Some of the major problems facing mankind in this century involve earth science, especially the generation of new energy sources for a growing world population, and engineers will be challenged to solve these problems. This minor will prepare engineering students to understand the natural operating systems of Earth and the tools and techniques used by earth scientists to understand and monitor these solid and fluid systems.

**Academic standards:** At least C– in each course in the minor. GPA ≥ 2.0 for all courses in the minor.

**Requirements**

At least six courses (≥ 18 credits), chosen as follows:

1. EAS 2200 The Earth System
2. At least two of these courses:

   EAS 3010 Evolution of the Earth System

   EAS 3030 Introduction to Biogeochemistry

   EAS 3040 Interior of the Earth

   EAS 3050 Climate Dynamics
3. Additional EAS courses at the 3000 level or higher. These may include, e.g., additional courses from the above lists, undergraduate research courses, and outdoor field courses.

## MASTER OF ENGINEERING DEGREES

The M.Eng. is a professional degree usually completed in two semesters. The curriculum offers advanced training, is practice-oriented, and is designed to assist engineers in development of their professional careers. Completion of the M.Eng. degree requires a design project rather than thesis research. The M.Eng. provides the technical expertise and leadership skills needed in business, government, and industry.

Office of Research and Graduate Studies, and Professional Education (RGS), 222 Carpenter Hall, www.engineering.cornell.edu/rgs.

The following one-year (30-credit) professional master of engineering (M.Eng.) degrees are offered (giving also the administering unit)

**M.Eng. (Aerospace Engineering):** mechanical and aerospace engineering

**M.Eng. (Biological and Environmental Engineering):** biological and environmental engineering

**M.Eng. (Biomedical Engineering):** biomedical engineering

**M.Eng. (Chemical Engineering):** chemical and biomolecular engineering

**M.Eng. (Civil and Environmental Engineering):** civil and environmental engineering

**M.Eng. (Computer Science):** computer science

**M.Eng. (Electrical and Computer Engineering):** electrical and computer engineering

**M.Eng. (Engineering Management):** civil and environmental engineering

**M.Eng. (Engineering Mechanics):** theoretical and applied mechanics

**M.Eng. (Engineering Physics):** applied and engineering physics

**M.Eng. (Geological Sciences):** earth and atmospheric sciences

**M.Eng. (Materials Science and Engineering):** materials science and engineering

**M.Eng. (Mechanical Engineering):** mechanical and aerospace engineering

**M.Eng. (Operations Research and Information Engineering):** operations research and information engineering

**M.Eng. (Systems Engineering):** systems engineering

Many Cornell baccalaureate engineering graduates spend a fifth year at Cornell, earning an M.Eng. degree, although the program is also open to qualified graduates of other schools.

Requirements for admission vary by program. In general, the standard M.Eng. application requirements include:

- Statement of purpose
- Complete transcripts from each college or university attended
- At least two letters of recommendation
- Graduate Record Examination (GRE) scores—may not be required by all M.Eng. programs

Many M.Eng. programs waive the GRE requirement and one of the letters of recommendation for students with Cornell Engineering B.S. degrees. Check with the appropriate office for specific program requirements. A list of links and general admission information is posted on www.engr.cornell.edu/grad/MEng.

Superior Cornell students who will have between 1 and 8 credits remaining in their last undergraduate semester may petition for early admission to the M.Eng. program. They spend the last semester in both programs, finishing up their B.S. degree and also doing their first semester of the M.Eng. program.

### Master of Engineering Minors and Concentrations

The following M.Eng. minors and concentrations are offered:

#### Minors

- bioengineering
- manufacturing
- engineering management
- systems engineering

#### Concentrations

- information technology
- financial engineering
- applied operations research
- data mining and analytical marketing
- technology management for ECE
- semester in strategic operations
- complex system development
- nanosystems

A table indicates which minors and concentrations are available to students and contains detailed descriptions: www.engineering.cornell.edu/student-services/rgs/upload/MEng-Minors-and-Concentrations-Grid.pdf.

### Cooperative Program with the Johnson Graduate School of Management

Undergraduates may be interested in a cooperative program at Cornell that leads to both master of engineering and master of business administration (M.B.A.) degrees. With appropriate curriculum planning, such a combined B.S./M.Eng./M.B.A. program can be completed in six years at Cornell, with time out for work experience. For undergraduates from other schools, it may be feasible to complete the M.Eng./M.B.A. program in two years, possibly with an intervening summer or time out for work experience if they do not already have it on coming to Cornell. This accelerated program often incorporates the 12-month M.B.A. program of the Johnson Graduate School of Management (JGSM).

Because 95 percent of the students in the JGSM have work experience, there will typically be a gap for work experience between the M.Eng. and M.B.A. portions of the program for students who do not already have it when beginning the M.Eng. portion.

For further details, visit Engineering Advising (167 Olin Hall), the M.Eng. office (222 Carpenter Hall), the JGSM office in Sage Hall, or the office of your intended undergraduate major.

### Lester Knight Scholarship Program

The Lester Knight Scholarship Program is designed to assist and encourage Cornell Engineering students and alumni interested in combining their engineering education with a business degree. The program offers two options or categories of financial support:

- Undergraduate Knight Scholarship
- Alumni Knight Scholarship

Each program has different qualifications and is open to Cornell engineering students and alumni at different stages of their educational or professional career. Participation in the program requires admission by each respective academic program (M.Eng, M.B.A.) as well as an application to participate in the Knight Scholarship Program.

Contact RGS or refer to the Knight Scholarship web site (www.engr.cornell.edu/knightscholarships) for program specifics.

## MASTER OF ENGINEERING (AEROSPACE ENGINEERING)

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 107 Upson Hall, 255-5250, www.mae.cornell.edu

The M.Eng. (Aerospace Engineering) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

The program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas. These include aerodynamics, acoustics and noise, turbulent flows, nonequilibrium flows, combustion, dynamics and control, and computational fluid dynamics.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty advisor. This program and any subsequent changes must also be approved by the chair of the MAE Master of Engineering committee. An individual student's curriculum includes a 4- to 8-credit design course, a minimum of 12 credits in aerospace engineering or a closely related field, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

Design projects must have an aerospace engineering design focus and have the close supervision of a faculty member. The projects may arise from individual faculty and student interests or from collaboration with industry.

All courses must be of true graduate nature. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have the approval of the MAE master of engineering chair.

Check with the MAE graduate field office (107 Upson Hall) for additional degree requirements.

Students enrolled in the M.Eng. (Aerospace Engineering) degree program may take courses that also satisfy the requirements of the bioengineering, engineering management, or systems engineering minors.

## MASTER OF ENGINEERING (BIOLOGICAL AND ENVIRONMENTAL ENGINEERING)

Offered by the Department of Biological and Environmental Engineering

Contact: 207 Riley-Robb Hall, 255-2173, www.bee.cornell.edu

This degree is intended primarily for students who plan to enter engineering practice. The program is planned as an extension of an undergraduate major in biological and environmental engineering but can accommodate graduates of other engineering disciplines. The required 30 credits of courses are intended to strengthen the students' fundamental knowledge of engineering and develop their design skills. Of the 30 credits, 3 to 9 are earned for an engineering design project that culminates in a written and oral report.

Students may concentrate in one of the following areas: biological engineering, energy, environmental engineering, environmental management, food processing engineering, international agriculture, local roads, machine systems, soil and water engineering, and structures and environment. Elective courses are chosen from among engineering subject areas relevant to the student's interests and design project. Courses in technical communication, math, biology, and the physical sciences may also be taken as part of a coherent program. Students can qualify for the Dean's Certificate in energy, manufacturing, or bioengineering by choosing their design project and a number of electives from the designated topic areas.

## MASTER OF ENGINEERING (BIOMEDICAL ENGINEERING)

Offered by the Department of Biomedical Engineering

Contact: 361 Olin Hall, 255-2573, www.bme.cornell.edu

Our mechanistic understanding of biology has increased rapidly over the past 20 years, and many expect biology to drive engineering and technology in the next 50 years in much the same way that physics drove them in the 20th century. As biology has become more mechanistic, the opportunities to apply engineering approaches have increased enormously. Simultaneously, humanitarian needs and economic opportunities for the application of engineering to improve health care have increased significantly. Engineers who understand biology and can apply their knowledge and skills to improve human health are increasingly in demand. A professional degree in biomedical engineering will prepare students to fill this increasing critical need.

The breadth and depth of knowledge needed in biomedical engineering makes a four-year B.S. degree program impractical. By combining the M.Eng. (Biomedical Engineering) with a strong B.S. program, a student can obtain the knowledge and skills necessary to be an effective professional biomedical engineer.

Students will acquire an in-depth knowledge of an essential area of biomedical engineering as well as a broad perspective of the biomedical engineering discipline that complements their undergraduate education in engineering or science. Graduates will be equipped to design biomedical devices and develop therapeutic strategies within the bounds of health care economics, the needs of patients and physicians, the regulatory environment for medical devices and pharmaceuticals, and stringent ethical standards.

Students will acquire depth by extending undergraduate concentrations, by selecting one of three areas for concentrated study, and by completing a design project in their area of concentration. The areas are biomedical mechanics and materials; bioinstrumentation/diagnostics; and drug delivery and cellular/tissue engineering. Design projects will be carried out in teams to take advantage of the diversity of student backgrounds and, when possible, projects will be done in collaboration with industrial or clinical partners.

Students from a wide variety of backgrounds in engineering and science are encouraged to apply. They are expected to have completed two semesters of calculus-based physics, at least three semesters of math, starting with calculus, and introductory computer science.

A knowledge of molecular- and cellular-base biomedical engineering and engineering analysis of physiological systems at the level of BME 3010, 3020, 4010, and 4020 is highly recommended. This knowledge can be demonstrated through appropriate undergraduate course work (at least C in each class). Students lacking the appropriate background may need to complete additional courses (beyond the normal 30 credits) to demonstrate appropriate knowledge in these two subject areas.

## MASTER OF ENGINEERING (CHEMICAL ENGINEERING)

Offered by the School of Chemical and Biomolecular Engineering

Contact: 358 Olin Hall, 255-4550, www.cheme.cornell.edu

This degree is awarded at the end of one year of graduate study with successful completion of 30 credits of required and elective courses in technical fields including engineering, math, chemistry, physics, and business administration. Some courses emphasize design and optimization based on the economic factors that affect design alternatives for processes, equipment, and plants. General admission and degree requirements are described at the beginning of the section "Master of Engineering Degrees."

Specific requirements include

1. 12 credits in CHEME courses distributed among chemical and biomolecular engineering fundamentals. One required from among CHEME 7110, 7310, and 7510 and the remainder in chemical and biomolecular engineering applications (partial list: CHEME 4800, 4810, 4840, 5200, 5209, 5430, 5720, 6310, 6400, and 6610).
2. A minimum of 3 credits of an individual or group project, CHEME 5650.
3. Knowledge of business practices and techniques for pollution abatement and control. This knowledge may have already been acquired by students as undergraduates. If not, then CHEME courses (e.g., CHEME 5720 and 6610) or other courses covering these topics are required.

## MASTER OF ENGINEERING (CIVIL AND ENVIRONMENTAL ENGINEERING)

Offered by the School of Civil and Environmental Engineering

Contact: 219 Hollister Hall, 255-7560, www.cee.cornell.edu

The Master of Engineering degree is a course work and project-oriented program. It is normally completed in two semesters of intensive study. Thirty credit hours are required, consisting of course work in a major concentration and a supporting area, as well as a design project.

Students may focus their studies in one of six major subject areas: environmental and water resource systems engineering, environmental fluid mechanics and hydrology, environmental processes, geotechnical engineering, structural engineering, and transportation systems engineering. Courses in supporting areas come from many disciplines, including architecture, computer science, economics, engineering management, historic preservation, materials science, microbiology and operations research to name just a few.

## MASTER OF ENGINEERING (COMPUTER SCIENCE)

Offered by the Department of Computer Science

Contact: 322 Upson Hall, 255-8720, www.cs.cornell.edu/grad/meng

The M.Eng. program in computer science can be started in either the fall or spring semester. This program is designed to develop expertise in system design and implementation in many areas of computer science, including computer networks, Internet architecture, fault-tolerant and secure systems, distributed and parallel computing, high-performance computer architecture, databases and data mining, multimedia systems, computer vision, computational tools for finance, computational biology (including genomics), software engineering, programming environments, and artificial intelligence.

A typical program includes several upper-division and graduate courses and a faculty-supervised project. The flexible requirements allow students to build up a program that closely matches their interests. In fact, slightly under half the courses may be taken outside the computer science department (many students choose to take several business administration courses). Project work, which may be done individually or in a small group, can often be associated with ongoing research in the Department of Computer Science in one of the areas listed above.

Cornell seniors may use the early admission option to effectively co-register for the M.Eng. program while completing the undergraduate degree. This option can be started in either the fall or spring semester. It applies to students who have 1 to 8 credits remaining to complete their undergraduate program. All remaining undergraduate degree requirements must be satisfied by the end of the first semester the student is enrolled in the M.Eng. "early admit" program.

Undergraduates majoring in computer science may be interested in a program that can lead, in the course of six years, to B.S., M.Eng. (Computer Science), and M.B.A. degrees. See "Master of Engineering Degrees."

## MASTER OF ENGINEERING (ELECTRICAL AND COMPUTER ENGINEERING)

Offered by the School of Electrical and Computer Engineering

Contact: Student Services Office, 223 Phillips Hall, 255-8414, www.ece.cornell.edu/aca-meng.cfm

The M.Eng. (Electrical) degree program prepares students either for professional work in Electrical and Computer Engineering and closely related areas or for further graduate study in a doctoral program. The M.Eng. degree differs from the master of science degree mainly in its emphasis on professional skills, engineering design, and analysis skills rather than basic research.

The program requires 30 credits of advanced technical course work beyond that expected in a typical undergraduate program, including at least four graduate-level courses in Electrical and Computer Engineering. The required Electrical and Computer Engineering design project may account for 3 to 8 credits of the M.Eng. program. Occasionally, students take part in very extensive projects and may petition to increase the project component to 10 credits. Students with special career goals, such as engineering management, may apply to use up to 11 credits of approved courses that have significant technical content but are taught in disciplines other than engineering, math, or the physical sciences.

Although admission to the M.Eng. (Electrical and Computer Engineering) program is highly competitive, all well-qualified students are urged to apply. Further information is available at the web site listed above.

## MASTER OF ENGINEERING (ENGINEERING MANAGEMENT)

The M.Eng. (Engineering Management) program is designed for engineers who want to stay in a technical environment but advance to managerial roles. Students learn to identify problems, formulate and analyze models to understand these problems, and interpret the results of analyses for managerial action.

A student's program of study is designed individually in consultation with an academic advisor and then submitted to the school's Professional Degree Committee for approval.

For the M.Eng. (Engineering Management) program, the requirements are:

1. Three core courses: These include: CEE 5800 Project Management, CEE 5930 Engineering Management Methods, and CEE 5910 Management Project.
2. Two focus courses, from a list that includes CEE 5960, CEE 5970, CEE 5980, and CEE 6900.
3. Two managerial breadth courses, including one in finance/accounting and one focused on behavior.
4. Three disciplinary or functional electives.

The School of Civil and Environmental Engineering cooperates with the Johnson Graduate School of Management in a joint program leading to both Master of Engineering and Master of Business Administration degrees. See the beginning of the section “Master of Engineering Degrees.”

## MASTER OF ENGINEERING (ENGINEERING MECHANICS)

Offered by the Department of Theoretical and Applied Mechanics

Contact: 212 Kimball Hall, 255-0988, www.tam.cornell.edu/meng1.html

This two-semester professional degree program stresses applications of Engineering Mechanics and Applied Mathematics and Modeling. The centerpiece of the program is a project, either single or team-based, on important real-world problems.

Engineering Mechanics: Students in this program will deepen and broaden their knowledge of mechanics as applied to different material systems. The course work centers on additional study of solid mechanics, fracture mechanics, materials and computational methods widely used in industries such as the finite element method. Potential employers are companies interested in computer modeling of mechanical systems and failure and reliability analysis.

Applied Mathematics and Modeling: Students in this program do course work in mathematical modeling and computational methods. They will have great flexibility in their choice of studies. Students who graduate from this program are in a good position to pursue higher degrees or work for financial or informational organizations.

Laboratories: TAM has many laboratories related to research areas and courses of study for the M.Eng. program:

- Ultrasonic and Materials Characterization Laboratory—*Wolfgang Sachse*
- Bio-robotics and Locomotion Laboratory—*Andy Ruina*
- Granular Flow Research Laboratory—*Jim Jenkins*
- Composites Laboratory—*Leigh Phoenix and Petru Petrina*
- Fracture Mechanics Laboratory—*Alan Zehnder*
- Dynamics Laboratory—*Dan Mittler*
- Mechanics of Solids Laboratory—*Dan Mittler*
- Biological Fluid Dynamics Laboratory—*Jane Wang*

Course Work:

(project 10–12 credit hours)

**Current Interesting Projects**

1. Animal, Human and Robotic Locomotion—*Andy Ruina*
2. Dynamical Systems—*Richard Rand*
3. Stress Rupture Testing of High-Performance Fibers and Yarns—*S. Leigh Phoenix*
4. Mathematics of Finance (capital budgeting, economic analysis Scholes—Black Diffusion Theory)—*K. Bingham Cady*
5. Fracture and Reliability—*Hui, Phoenix, Zehnder*
6. Response Theory—*K. Bingham Cady*
7. Nuclear Reactor Theory—*K. Bingham Cady*
8. Determination of Elastic Constance of Composite Materials Using Ultrasonics—*Wolfgang Sachse*

**Engineering Mechanics**

*Fall semester*

| *Course* | *Title* | *Credits* |
|---|---|---|
| TAM 6630 | Solid Mechanics I | 4 |
| TAM 5700 | Intermediate Dynamics | 3 |
| or | | |
| TAM 6100 | Methods of Applied Mathematics I | 3 |
| TAM 8000 | Seminar | 1 |

*Spring semester*

| | | |
|---|---|---|
| CEE 7770 | Special Topics in Structural Engineering | 3 |
| or | | |
| TAM 7130 | Fracture | 3 |
| TAM 6550 | Composite Materials | 4 |
| MSE 5820 | Mechanical Properties of Material, Processing and Design | 4 |
| MAE 5700 | Finite Element Analyses for Mechanical and Aerospace Design | 4 |
| TAM 8000 | Seminar | 1 |

**Applied Mathematics and Modeling**

*Fall semester*

| | | |
|---|---|---|
| TAM 5700 | Intermediate Dynamics | 3 |
| TAM 6100 | Methods of Applied Mathematics I | 3 |
| CEE 7710 | Stochastic Mechanics in Science and Engineering | 3 |
| TAM 8000 | Seminar | 1 |

*Spring semester*

| | | |
|---|---|---|
| TAM 5700 | Intermediate Dynamics | 3 |
| TAM 6110 | Methods of Applied Mathematics I | 3 |
| TAM 6710 | Hamiltonian Dynamics | 3 |
| or | | |
| TAM 6740 | Nonlinear Vibrations | 3 |
| MAE 5700 | Finite Element Analyses for Mechanical and Aerospace Design | 4 |
| CEE 6720 | Introduction to the Finite Element Method | 3 |

## MASTER OF ENGINEERING (ENGINEERING PHYSICS)

Offered by the School of Applied and Engineering Physics

Contact: 212 Clark Hall, 255-5198, www.aep.cornell.edu

The M.Eng. (Engineering Physics) degree may lead directly to employment in engineering design and development or may be a basis for further graduate work. Students have the opportunity to broaden and deepen their preparation in the general field of applied physics, or they may choose the more specific option of preparing for professional engineering work in a particular area such as laser and optical technology, nanostructure science and technology, device physics, materials characterization, or software engineering. Wide latitude is allowed in the choice of the required design project.

Students plan their program in consultation with the program chair. The objective is to provide a combination of a good general background in physics and introductory study in a specific field of applied physics. Candidates may enter with an undergraduate preparation in physics, engineering physics, or engineering. Those who have majored in physics usually seek advanced work with an emphasis on engineering; those who have majored in an engineering discipline generally seek to strengthen their physics base. Candidates coming from industry usually want instruction in both areas. Students granted the degree will have demonstrated competence in an appropriate core of basic physics. If this has not been accomplished before entering the M.Eng. program, undergraduate classes in electricity and magnetism, classical mechanics, and quantum mechanics may be required in addition to the classes taken to satisfy the M. Eng. requirements.

The degree requires 30 credits of graduate-level courses or their equivalent, with at least C– in each course, and distributed as follows:

1. a design project in applied science or engineering with a written final report (6 to 12 credits)
2. an integrated program of graduate-level courses, as discussed below (17 to 23 credits)
3. a required special-topics seminar course (1 credit)

The design project, which is proposed by the student and approved by the program chair, is carried out on an individual basis under the guidance of a member of the university faculty. It may be experimental or theoretical in nature; if it is not experimental, a laboratory physics course is required.

The individual program of study consists of a compatible sequence of courses focused on a specific area of applied physics or engineering. Its purpose is to provide an appropriate combination of physics and physics-related courses (applied math, statistical mechanics, applied quantum mechanics) and engineering electives (e.g., courses in biophysics, chemical engineering, electrical engineering, materials science, computer science, mechanical engineering, or nuclear engineering). Additional science and engineering electives may be included. Some courses at the senior level (4000) are acceptable for credit toward the degree; other undergraduate courses may be required as prerequisites but may not be credited toward the degree.

## MASTER OF ENGINEERING (GEOLOGICAL SCIENCES)

Offered by the Department of Earth and Atmospheric Sciences

Contact: 2124 Snee Hall, 255-5466, www.eas.cornell.edu

The one-year M.Eng. (Geological Sciences) degree program provides future professional geologists or engineers with the geological and engineering background they will need to analyze and solve engineering problems that involve geological variables and concepts. Individual programs are developed within two established options: geohydrology and environmental geophysics.

Incoming students are expected to have a strong background in mathematics, the physical sciences, and chemistry and have a strong interest and substantial background in the geological sciences. The 30-hour M.Eng. program is intended to extend and broaden this background to develop competence in four subject categories. Typical categories for the geohydrology option are porous media flow, geology, geochemistry, and numerical modeling. Typical categories for the environmental geophysics option are geophysics, geology, porous media fluid flow, and computer methods. The courses a student selects in a category will vary depending on the student's background. No courses may be required in some categories, and the categories can be adjusted to the student's interest and needs. Alternatives to numerical modeling in the geohydrology option could be economics or biochemistry, for example. To count toward the 30-credit degree requirement, courses must be at a graduate or advanced undergraduate level.

At least 10 of the 30 hours in the program must involve engineering design. Much of this requirement is normally met through a design project, which can account for over a third of the program (12 of 30 credits) and must constitute at least 3 credits. The design project must involve a significant geological component and lead to concrete conclusions or recommendations of an engineering nature. The project topic can be drawn from a student's nonacademic work experience but carried out or further developed with advice from a Cornell faculty member with expertise in the project area selected by the student. A design project in geohydrology would normally involve groundwater flow and mass transport. A design project in environmental geophysics might involve implementation of a field survey using seismological, geoelectrical, or ground-penetrating radar methods to map subsurface stratigraphic or structural features that control groundwater flow or contamination at a site. Projects are presented both in written form and orally in a design seminar at the end of the year.

## MASTER OF ENGINEERING (MATERIALS SCIENCE AND ENGINEERING)

Offered by the Department of Materials Science and Engineering

Contact: 214 Bard Hall, 255-9159, www.mse.cornell.edu

Students who have completed a four-year undergraduate program in engineering or the physical sciences can be considered for admission into the M.Eng. (Materials Science and Engineering) program. This 30-credit program includes course work and a master's design project. The project, which requires individual effort and initiative, is carried out under the supervision of a faculty member. Twelve credits are devoted to the project, which is normally experimental in nature, although computational or theoretical projects are also possible.

Courses for the additional 18 credits are selected from the graduate-level classes in materials science and engineering and from other related engineering fields approved by the faculty. Typically half of the courses are from MSE. One 3-credit technical elective must include advanced math (modeling, computer application, or computer modeling) beyond the MSE undergraduate requirements.

## MASTER OF ENGINEERING (MECHANICAL ENGINEERING)

Offered by the Sibley School of Mechanical and Aerospace Engineering

Contact: 107 Upson Hall, 255-5250, www.mae.cornell.edu

The M.Eng. (Mechanical Engineering) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

Candidates may concentrate on any of a variety of specialty areas, including biomechanical engineering, combustion, propulsion and power systems, fluid mechanics, heat transfer, materials and manufacturing engineering, and mechanical systems and design.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty advisor. This program and any subsequent changes must also be approved by the chair of the MAE Master of Engineering committee. An individual student's curriculum includes a 4- to 8-credit design course, a minimum of 12 credits in mechanical engineering or a closely related field, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have a mechanical engineering design focus and have the close supervision of a faculty member.

All courses must be of true graduate nature. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have special approval of the MAE master of engineering chair.

The technical electives may be courses of appropriate level in math, physics, chemistry, or engineering; a maximum of 3 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives.

Check with the MAE graduate field office (107 Upson Hall) for additional degree requirements.

Students enrolled in the M.Eng. (Mechanical Engineering) degree program may take courses that also satisfy the requirements of the bioengineering, engineering management, or systems manufacturing minors.

## MASTER OF ENGINEERING (OPERATIONS RESEARCH AND INFORMATION ENGINEERING)

Offered by the School of Operations Research and Information Engineering

Contact: 201 Rhodes Hall, 255-9128, www.orie.cornell.edu

This professional degree program stresses applications of operations research. The centerpiece of the program is a team-based project on a significant real-world problem. The course work centers on additional study of analytical techniques, with particular emphasis on the design or improvement of systems and processes in manufacturing, information, finance, and service organizations.

General admission and degree requirements are described in the introductory "Degree Programs" section. The ORIE M.Eng. program is designed to serve two groups of students: graduates of the undergraduate major in ORE who wish to deepen their practical knowledge of the field, and qualified undergraduates from other fields at Cornell and programs in the United States and abroad who want to complement their engineering or technical backgrounds with a solid foundation in operations research and information engineering.

For admission, the entering student should have completed an introductory course in probability and statistics, an intermediate-level course in computer science, as well as four semesters of mathematics, including differential equations, linear algebra, and multivariate calculus. For the financial engineering concentration, the entering student must also have completed an intermediate-level probability course and a basic finance course.

Program requirements include a core of ORIE courses plus technical electives chosen from a broad array of offerings. There are several concentrations, each requiring a particular set of electives plus a specific project course. The concentrations include applied operations research, financial engineering, information technology, strategic operations (which incorporates the Semester in Strategic Operations immersion at JGSM), data mining and analytical marketing, and manufacturing and industrial engineering. Students may also minor in systems engineering. Several of these options are offered jointly with other Cornell departments and schools and provide the opportunity to interact with students and specialists in other engineering fields and in business. For information about the manufacturing and industrial engineering concentration, contact the Center for Manufacturing Enterprise, 291 Grumman Hall, 255-5545; about the Semester in Strategic Operations, 304 Sage Hall, 255-4691; about systems engineering, 280 Rhodes Hall, 254-8998, and for all others, 201 Rhodes Hall, 255-9128. The applied operations research concentration is designed to be completed in two semesters. The financial engineering concentration is highly specialized and typically requires three semesters to complete. This permits an industry internship in the summer between semesters as well as a third semester of study in New York City.

For scheduling reasons, certain other concentrations may entail an additional summer or semester, depending on the student's preparation.

The manner in which the M.Eng. project requirement is met depends on the chosen concentration. Common elements in all project experiences include working as part of a team of three to five students on an engineering design problem, meeting with a faculty advisor on a regular basis, and presenting the final results to the project sponsor. Most projects have industrial client sponsors and address problems that actually exist in practice.

Applicants who already hold graduate degrees in other fields may be interested in the possibility of completing both an M.Eng. and an M.B.A program within a period of two years, possibly with intervening work experience. This possibility incorporates the Johnson Graduate School of Management (JGSM) "Accelerated MBA" (formerly Twelve-Month Option).

Additional program requirements are described in the *Master of Engineering Handbook* and on the web. For further details, see the contact information at the beginning of this section.

## MASTER OF ENGINEERING (SYSTEMS ENGINEERING)

Offered by The Systems Engineering Program

Contact: 206 Rhodes Hall, 254-8998, www.systemseng.cornell.edu

Today's engineering environment is increasingly complex and rapidly changing. Due in part to emerging technologies and globalization, engineers must think in terms of complex, integrated, globally optimized solutions to devise designs that address the complexity of the real world. Success in this environment requires a comprehensive understanding of systems engineering.

The Systems Engineering Program emphasizes the fundamentals of requirements analysis, systems architecture, product development, project management, optimization, simulation, and systems analysis. The program's strength in these areas helps promote an understanding of the systems process throughout an organization and prepares students to transition from designing and managing independent engineering components and projects to creating integrated solutions that meet customer needs.

The M.Eng. (Systems Engineering) program is designed for students with a solid disciplinary background who want to specialize in Systems Engineering. It requires a minimum of 30 credit hours. Students must complete the following required courses:

Applied Systems Engineering (3 credits)

Systems Architecture, Behavior, and Optimization (3 credits)

Project Management (CEE 5800) (4 credits)

Systems Engineering Design Project (6–8 credits)

Approved electives account for the remaining credits to reach the minimum of 30 credits required for the degree and are to be chosen from the following areas:

Systems Modeling and Analysis (at least one course)

Courses that enrich the understanding of generic methods to design and analyze systems including courses in simulation, feedback and control, decision-making, or risk analysis.

Systems Applications

Courses that provide depth in the design and operation of specific systems such as power, communication, software, manufacturing, or transportation.

Systems Management (at most one course):

Courses that enhance student understanding of the management activities and processes which are necessary to successfully design and operate systems.

In addition to the Master of Engineering degree in Systems Engineering, the Systems Engineering Program offers a second course of study: the minor in Systems Engineering. The SE minor is designed for students who want a concentration in Systems Engineering as part of the Master of Engineering degree in another engineering discipline.

## ENGINEERING COURSES

Courses offered in the College of Engineering are listed under the various departments and schools.

Courses are identified with a standard abbreviation followed by a four-digit number.

| | |
|---|---|
| Engineering Communications | ENGRC |
| Engineering Distribution | ENGRD |
| Engineering General Interest | ENGRG |
| Engineering Introductions | ENGRI |
| Biological and Environmental Engineering | BEE |
| Applied and Engineering Physics | AEP |
| Chemical and Biomolecular Engineering | CHEME |
| Civil and Environmental Engineering | CEE |
| Computer Science | CS |
| Computing and Information Science | CIS |
| Earth and Atmospheric Sciences | EAS |
| Electrical and Computer Engineering | ECE |
| Information Science | INFO |
| Materials Science and Engineering | MSE |
| Mechanical and Aerospace Engineering | MAE |
| Nuclear Science and Engineering | NSE |
| Operations Research and Information Engineering | ORIE |
| Systems Engineering | SYSEN |
| Theoretical and Applied Mechanics | TAM |

## ENGINEERING COMMON COURSES

### Engineering Communications Courses

Courses in this category, offered by the Engineering Communications Program (ECP), develop writing and oral-presentation skills needed by engineers.

**ENGRC 3020 Writing-intensive Opportunity: Practicum in Technical Writing**

Fall, spring. 1 credit.

One-credit attachment to an existing engineering course that is not one of the officially designated W-I courses. It may be taken more than once, with different courses by permission of a particular engineering faculty member.

**ENGRC 3340 Independent Study in Engineering Communications**

1–3 credits, variable. Letter grades. TBA with instructor.

Members of the ECP occasionally give independent (also called "directed") studies in engineering communications, typically with students who are ready for advanced work in technical writing. A student doing a directed study works one-on-one with an ECP instructor to pursue an aspect of professional communications in more depth than is possible in the ECP's regular courses. Various types of projects are possible, e.g., studying forms of technical documentation, creating user manuals, analyzing and producing technical graphics, reading and writing about problems in engineering practice, and writing about technical topics for the public.

**ENGRC 3350 Communications for Engineering Managers (LA)**

Fall, spring. 3 credits. Fulfills college technical-writing requirement. May be used as free or approved elective in expressive arts. Intended for juniors and seniors. Limited to 20 students per sec. Prerequisite: two first-year writing seminars and major affiliation.

This seminar focuses on communications in organizational contexts common to engineering graduates. Topics may include internal and external communications; balancing visual and verbal elements in documents and oral presentations; teamwork and leadership; running and attending meetings; management strategies; and communicating with colleagues, superiors, subordinates, and clients. Students develop writing and management strategies that they apply in individual and team assignments. They learn how to organize technical and managerial information, articulate and support ideas, and communicate with technical and nontechnical audiences.

**ENGRC 3500 Engineering Communications (LA)**

Fall and spring. 3 credits. Designed for juniors and seniors. Fulfills college technical-writing requirement. May be used as free or approved elective in expressive arts. Limited to 20 students per sec. Prerequisite: two first-year writing seminars and affiliation with a major.

This course prepares students for important communication activities. They write various types of documents (e.g., letters, memos, executive summaries, problem analyses, proposals, progress reports), give oral presentations, and incorporate graphics in their oral and written work. Students learn how to communicate specialized information to different audiences (e.g., technical and nontechnical people, colleagues and clients, peers and supervisors, in-house departments, and government agencies), work in teams, and address organizational and ethical issues. The course material is drawn from professional contexts, principally engineering, and it generates lively discussion. The class size ensures close attention to each student's work. (Note: Absences are limited to three, after which sharp penalties occur.)

## Engineering Distribution Courses

Courses in this category are sophomore-level courses cross-listed with a department. These courses are intended to introduce students to more advanced concepts of engineering and may require pre- or corequisites.

**ENGRD 2020 Mechanics of Solids (also TAM 2020)**

Fall, spring. 4 credits. Prerequisite: PHYS 1112, co-registration in MATH 1920, or permission of instructor. All students must take a lab section. Staff.

Covers principles of statics, force systems, and equilibrium; frames; mechanics of deformable solids, stress, strain, statically indeterminate problems; mechanical properties of engineering materials; axial force, shearing force, bending moment, thermal stress, stretching; bending and torsion of bars. Laboratory experiments demonstrate basic principles of solid mechanics.

**ENGRD 2030 Dynamics (also TAM 2030)**

Fall, spring. 3 credits. Prerequisite: ENGRD/TAM 2020, co-registration in MATH 2930, or permission of instructor. All students must take a lab and a section.

Newtonian dynamics of a particle, systems of particles, a rigid body. Kinematics, motion relative to a moving frame. Impulse, momentum, angular momentum, energy. Rigid-body kinematics, angular velocity, moment of momentum, the inertia tensor. Euler equations, the gyroscope. Laboratory experiments demonstrate basic principles of dynamics.

**ENGRD 2100 Introduction to Circuits for Electrical and Computer Engineers (also ECE 2100)**

Fall, spring. 4 credits. Corequisites: MATH 2930 and PHYS 2213. All students must take a lab and a section.

First course in electrical circuits and electronics. Establishes the fundamental properties of circuits with application to modern electronics. Topics include circuit analysis methods, operational amplifiers, basic filter circuits, and elementary transistor principles. The laboratory experiments are coupled closely with the lectures.

**ENGRD 2110 Object-Oriented Programming and Data Structures (also CS 2110)**

Fall, spring, summer. 3 credits. Prerequisite: CS 1110, CS 1130, or CS 1113 or CS 1112 if completed before fall 2007, or equivalent course in Java or C++.

Intermediate programming in a high-level language and introduction to computer science. Topics include program structure and organization, object-oriented programming (classes, objects, types, sub-typing), graphical user interfaces, algorithm analysis (asymptotic complexity, big "O" notation), recursion, data structures (lists, trees, stacks, queues, heaps, search trees, hash tables, graphs), simple graph algorithms. Java is the principal programming language.

**ENGRD 2190 Mass and Energy Balances (also CHEME 2190)**

Fall. 3 credits. Corequisite: physical chemistry course or permission of instructor. S. Daniel.

Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Introduction to phase equilibria for multicomponent systems. Examples drawn from a variety of chemical and biomolecular processes.

**ENGRD 2210 Thermodynamics (also MAE 2210)**

Fall, spring, may be offered summer. 3 credits. Prerequisites: MATH 1920, Calculus for Engineers, and PHYS 1112, Physics I, Mechanics.

Presents the definitions, concepts, and laws of thermodynamics. Topics considered include the first and second laws, thermodynamic property relationships, and applications to vapor and gas power systems, refrigeration, and heat pump systems. Examples and problems are related to contemporary aspects of energy and power generation and to broader environmental issues.

**ENGRD 2300 Introduction to Digital Logic Design (also ECE 2300)**

Fall, spring. 4 credits. Prerequisite: CS 1110 or CS 1112.

Introduction to the design and implementation of practical digital circuits. Topics include transistor network design, Boolean algebra, combinational circuits, sequential circuits, finite state machine design, and analog and digital converters. Design methodology using both discrete components and hardware description languages is covered in the weekly laboratory portion of the course.

**ENGRD 2510 Engineering for a Sustainable Society (also BEE 2510)**

Fall. 3 credits. Pre- or corequisite: MATH 2930. B. A. Ahner.

Case studies of contemporary environmental issues including pollutant distribution in natural systems, air quality, hazardous waste management, and sustainable development. Emphasis is on the application of mathematics, physics, and engineering sciences to solve energy and mass balances in environmental sciences. Students are introduced to the basic chemistry, ecology, biology, ethics, and environmental legislation relevant to the particular environmental problem. BEE students must complete either BEE 2510 or BEE 2600 according to their academic plan. BEE students who complete both BEE 2510 and BEE 2600 receive engineering credit for only one of these courses.

**ENGRD 2520 The Physics of Life (also AEP 2520)**

Fall. 3 credits. Prerequisites: MATH 1920, CHEM 2070 or 2090, and co-registration in or completion of PHYS 2213. L. Pollack.

Introduces the physics of biological macromolecules (e.g., proteins, DNA, RNA) to students of the physical sciences or engineering who have little or no background in biology. The macromolecules are studied from three perspectives. First, the biological role or function of each class of macromolecules is considered. Second, a quantitative description of the physical interactions that determine the behavior of these systems is provided. Finally, techniques that are commonly used to probe these systems, with an emphasis on current research, are discussed.

**ENGRD 2600 Principles of Biological Engineering (also BEE 2600)**

Fall. 3 credits. Pre- or corequisite: MATH 2930. A. J. Baeumner.

Focuses on the integration of biological systems with engineering, math, and physical principles. Students learn how to formulate equations for biological systems in class and practice it in homework sets. Topics range from molecular principles of reaction kinetics and molecular binding events to macroscopic applications, such as energy and mass balances of bioprocessing and engineering design of implantable sensors. BEE students must complete either BEE 2510 or BEE 2600 according to their academic plan. BEE students who complete both BEE 2510 and BEE 2600 receive engineering credit for only one of these courses.

**ENGRD 2610 Mechanical Properties of Materials: From Nanodevices to Superstructures (also MSE 2610)**

Fall. 3 credits. Prerequisite: MATH 1910. Corequisite: PHYS 1112 or permission of instructor. S. P. Baker.

Examines the mechanical properties of materials (e.g., strength, stiffness, toughness, ductility) and their physical origins. Topics include the relationship of elastic, plastic, and fracture behavior to microscopic structure in metals, ceramics, polymers, and composite materials. Effects of time and temperature on materials properties, and considerations for design and optimal performance of materials in engineered objects and biological tissues.

**ENGRD 2620 Electronic Materials for the Information Age (also MSE 2620)**

Spring. 3 credits. Prerequisite: MATH 1920. Corequisite: PHYS 2213 or permission of instructor. G. Malliaras.

Examines the electrical and optical properties of materials. Topics include the mechanism of electrical conduction in metals, semiconductors and insulators, the tuning of electrical properties in semiconductors, the transport of charge across metal/semiconductor and semiconductor/semiconductor junctions, and the interaction of materials with light. Applications in electrophotography, solar cells, electronics, and display technologies are discussed.

**ENGRD 2640 Computer-Instrumentation Design (also AEP 2640)**

Fall, spring. 3 credits. Prerequisite: CS 1110; permission of instructor for seniors. 1 lec, 1 lab. T. Cool.

Covers the use of a small computer in an engineering or scientific research lab. The experiments and devices investigated include: analog to digital converters (ADC), digital to analog converters (DAC), digital input/output (I/O), counter/timers, serial port communications, digital temperature control, error analysis, nonlinear least squares fitting of experimental data, viscosity of fluids, a robot arm, and thermal diffusion. C++ programming and graphical programming with LabVIEW™ are used for computer interfacing to hardware. Students develop effective written communication skills in the context of science and engineering. They prepare progress reports, technical reports, and formal articles based on the experiments.

**ENGRD 2700 Basic Engineering Probability and Statistics**

Fall, spring, summer. 3 credits. Prerequisites: MATH 1910 and 1920. MATH 2940 should be completed before or concurrently with ENGRD 2700.

Gives students a working knowledge of basic probability and statistics and their application to engineering. Includes computer analysis of data and simulation. Topics include random variables, probability distributions, expectation, estimation, testing, experimental design, quality control, and regression.

**ENGRD 3200 Engineering Computation**

Spring. 3 credits. Prerequisites: CS 1112 and MATH 2930. Corequisite: MATH 2940. Recommended: completion of MATH 2940. P. J. Diamessis.

Introduction to numerical methods, computational mathematics, and probability and statistics. Development of programming and graphics proficiency with MATLAB and spreadsheets. Topics include: Taylor-series approximations, numerical errors, condition numbers, operation counts, convergence, and stability, probability distributions, hypothesis testing. Included are numerical methods for solving engineering problems that entail roots of functions, simultaneous linear equations, statistics, regression, interpolation, numerical differentiation and integration, and solution of ordinary and partial differential equations, including an introduction to finite difference methods. Applications are drawn from different areas of engineering. A group project uses these methods on a realistic engineering problem.

**ENGRD 3220 Introduction to Scientific Computation (also CS 3220)**

Spring, summer. 3 credits. Prerequisites: one programming course and MATH 2210 or 2940; knowledge of discrete probability and random variables at the level of CS 2800.

An introduction to elementary numerical analysis and scientific computation. Topics include interpolation, quadrature, linear and nonlinear equation solving, least-squares fitting, and ordinary differential equations. Uses the MATLAB computing environment. Stresses sectorization, efficiency, reliability, and stability. Special lectures cover computational statistics.

## Courses of General Interest

Courses in this category are of general interest and cover technical, historical, and social issues relevant to the engineering profession. These courses may also include seminar or tutorial type courses.

**ENGRG 1009 Cooperative Workshop for CHEM 2090**

Fall, spring. 1 credit. Corequisite: CHEM 2090. S–U grades only.

Academic Excellence Workshop for CHEM 2090. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in CHEM 2090.

**ENGRG 1011 Cooperative Workshop for CS 2110**

Fall, spring. 1 credit. Corequisite: CS 2110. S–U grades only.

Academic Excellence Workshop for CS 2110. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in CS 2110.

**ENGRG 1050 Engineering Seminar**

Fall. 1 credit. Prerequisite: freshman standing. S–U grades only.

First-year engineering students meet in groups of 18 to 20 students weekly with their faculty advisors. Discussions may include the engineering curriculum and student programs, what engineers do, the character of engineering careers, active research areas in the college and in engineering in general, and study and examination skills useful for engineering students. Groups may visit campus academic, engineering, and research facilities.

**ENGRG 1060 Exploration in Engineering Seminar**

Summer. 1 credit. Designed for junior and senior high-school students.

Introduction to several engineering fields, such as: bioengineering, chemical engineering, civil engineering, computer science, earth sciences, electrical and computer engineering, engineering physics, materials science, mechanical engineering, operations research. Hands-on experience in weekly labs, as well as design projects to introduce concepts of the engineering design process.

**ENGRG 1091 Cooperative Workshop for MATH 1910**

Fall. 1 credit. Corequisite: MATH 1910. S–U grades only.

Academic Excellence Workshop for MATH 1910. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 1910.

**ENGRG 1092 Cooperative Workshop for MATH 1920**

Fall, spring. 1 credit. Corequisite: MATH 1920. S–U grades only.

Academic Excellence Workshop for MATH 1920. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 1920.

**ENGRG 1093 Cooperative Workshop for MATH 2930**

Fall, spring. 1 credit. Corequisite: MATH 2930. S–U grades only.

Academic Excellence Workshop for MATH 2930. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 2930.

**ENGRG 1094 Cooperative Workshop for MATH 2940**

Fall, spring. 1 credit. Corequisite: MATH 2940. S–U grades only.

Academic Excellence Workshop for MATH 2940. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in MATH 2940.

**ENGRG 1010 Cooperative Workshop for CS 1110**

Fall, spring. 1 credit. Corequisite: CS 1110. S–U grades only.

Academic Excellence Workshop for CS 1110. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in CS 1110.

**ENGRG 1012 Cooperative Workshop for CS 1112**

Fall, spring. 1 credit. Corequisite: CS 1112. S–U grades only.

Academic Excellence Workshop for CS 1112. Weekly two-hour cooperative learning sessions. Peer-facilitated group works on problems at or above the level of course material, designed to enhance understanding of core concepts in CS 1112.

**ENGRG 2350 Career Development for Engineering**
Spring. 2 credits. Prerequisite: second-semester freshman or sophomore standing.
Introduces concepts and techniques that can be used now and in the future to set appropriate personal and professional career goals.

**ENGRG 2500 Technology in Society (also ECE/HIST 2500, STS 2501)**
Fall. 3 credits. Approved for humanities distribution.
Investigates the history of technology in Europe and the United States from ancient times to the present. Topics include the economic and social aspects of industrialization; the myths of heroic inventors like Morse, Edison, and Ford; the government's regulation of technology; the origins of mass production; and the spread of the automobile and microelectronics cultures in the United States.

**ENGRG 2980 Inventing an Information Society (also ECE/AMST 2980, HIST 2920, STS/INFO 2921)**
Spring. 3 credits. Approved for humanities distribution.
Explores the history of information technology from the 1830s to the present by considering the technical and social history of telecommunications, the electric-power industry, radio, television, computers, and the Internet. Emphasis is on the changing relationship between science and technology, the economic aspects of innovation, gender and technology, and other social relations of this technology.

**ENGRG 3230 Engineering Economics and Management (also CEE 3230)**
Spring, sometimes offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. Students must register under CEE 3230.
D. P. Loucks.
Introduction to engineering and business economics investment alternatives and to project management. Intended to give students a working knowledge of money management and how to make economic comparisons of alternatives involving future benefits and cost. The impact of inflation, taxation, depreciation, financial planning, economic optimization, project scheduling, and legal and regulatory issues are introduced and applied to economic investment and planning and project-management problems.

**[ENGRG 3570 Engineering in American Culture (also AMST/HIST 3570, STS 3571)**
Fall. 4 credits. Approved for humanities distribution. Next offered 2008–2009.
The history of engineering in the United States from 1800 to the present. Investigates the education of engineers, how engineering changed from a masculine profession to one more open to women, the building of monumental projects, public images of the engineer, enthusiasm and disasters, and engineering in a global setting.]

**ENGRG 3600 Ethical and Social Issues in Engineering (also STS 3601) (KCM)**
Spring. 3 credits. Open to sophomores.
Studies major ethical and social issues involved in engineering practice. The issues include responsibility for designing products that do not harm public health, safety, and welfare; rights of engineers in large corporations; risk analysis and the principle of informed consent; conflict of interest; whistle blowing; trade secrets; and broader concerns such as environmental degradation, cost of health care, computer ethics, and working in multinational corporations. Codes of ethics of the professional engineering societies, ethical theory, and the history and sociology of engineering are introduced to analyze these issues.

**ENGRG 4610 Entrepreneurship for Engineers (also MAE 4610, ORIE 4152)**
Fall. 3 credits. Prerequisite: upper-level engineers or permission of instructor.
For description, see MAE 4610.

**ENGRG 6780 Teaching Seminar**
Fall, spring. 1 credit. S–U grades only. Staff.
Independent study promoting reflection on teaching styles and experiences for teaching assistants in the College of Engineering. Participants must be concurrently fulfilling a TA assignment. Requirements include participation in the College of Engineering's TA Development Program, consisting of an initial one and one-half day training session, followed by one evening microteaching session early in the semester; participation in the TA midterm evaluation process, followed by a formal feedback session with program staff; and completion of a reflective journal on teaching experiences. Designed to provide TAs with the opportunity to process their understanding of teaching and learning through the formulation of questions, concepts, and theories related to their experiences.

## Introduction to Engineering Courses

Courses in this category are first-year level courses intended to introduce students to various aspects of engineering. They have no prerequisites and most are cross-listed with a department.

**ENGRI 1100 Lasers and Photonics (also AEP 1100)**
Fall. 3 credits.
Lasers have had an enormous impact on communications, medicine, remote sensing, and material processing. This course reviews the properties of light that are essential to understanding the underlying principles of lasers and these photonic technologies. There also is a strong, hands-on laboratory component in which the students build and operate a nitrogen laser and participate in several demonstration experiments such as holography, laser processing of materials, optical tweezers, and fiber optics.

**ENGRI 1101 Engineering Applications of Operations Research**
Fall, spring. 3 credits. Not open to ORIE upper-level majors.
Introduction to the problems and methods of operations research and industrial engineering focusing on problem areas (including inventory, network design, and resource allocation), the situations in which these problems arise, and several standard solution techniques. In the computational laboratory, students encounter problem simulations and use some standard commercial software packages.

**ENGRI 1110 Nanotechnology (also MSE 1110)**
Fall. 3 credits. E. Giannelis.
Nanotechnology has been enabling the Information Revolution with the development of even faster and more powerful devices for manipulation, storing, and transmitting information. In this hands-on course students learn how to design and manipulate materials to build devices and structures in applications ranging from computers to telecommunications to biotechnology.

**ENGRI 1120 Introduction to Chemical Engineering (also CHEME 1120)**
Fall. 3 credits. Prerequisite: first-year standing. T. M. Duncan.
Design and analysis of processes involving chemical change. Students learn strategies for design, such as creative thinking, conceptual blockbusting, and (re)definition of the design goal, in the context of contemporary chemical and biomolecular engineering. Includes methods for analyzing designs, such as mathematical modeling, empirical analysis by graphics, and dynamic scaling through dimensional analysis, to assess product quality, economics, safety, and environmental issues.

**ENGRI 1130 Water Treatment Design (also CEE 1130)**
Spring. 3 credits. M. L. Weber-Shirk.
Students learn how to design: reservoirs to provide water during droughts, aqueducts to transport water, and water treatment plants to prevent waterborne diseases. The course includes field trips, building a computer-controlled miniature water treatment plant, and exploring new technologies for making safe drinking water.

**ENGRI 1160 Modern Structures (also CEE 1160)**
Fall. 3 credits. W. Aquino.
Introduction to structural engineering in the 21st century—the challenges structural engineers face and the innovative approaches they are using to address them. Using case studies of famous structures, students learn to identify different structural forms and understand how various forms carry load-using principles of statics, mechanics, and material behavior. The historical, economic, social, and political context for each structure is discussed. Case studies of failures are used to explain how structures fail in earthquakes and other extreme events, and students are introduced to analytical and experimental approaches (shake table and wind tunnel testing) to quantifying loads on structures subjected to extreme events. Types of structures considered include skyscrapers, bridges, aircraft, and underground structures.

**ENGRI 1170 Introduction to Mechanical Engineering (also MAE 1170)**
Fall. 3 credits.
Introduction to fundamentals of mechanical and aerospace engineering. Students learn and understand materials characteristics, the behavior of materials, and material selection for performing engineering function. They also learn fundamentals of fluid mechanics, heat transfer, automotive engineering, engineering design and product development, patents and intellectual property, and engineering ethics. In the final project, students use the information learned to design and manufacture a product.

**[ENGRI 1180 Design Integration: DVDs and iPods (also TAM 1180)**
Spring. 3 credits. Next offered 2009–2010.
W. Sachse.
This course examines the broad range of systems and engineering technologies required to build today's remarkable music/data and video sources.]

**ENGRI 1190 Biomaterials for the Skeletal System (also MSE 1190)**

Fall. 3 credits. D. Grubb.

Biomaterials are at the intersection of biology and engineering. This course explores natural structural materials in the human body, their properties and microstructure, and their synthetic and semi-synthetic replacements. Bones, joints, teeth, tendons, and ligaments are used as examples, with their metal, plastic, and ceramic replacements. Topics include strength, corrosion, toxicity, wear, and biocompatibility. Case studies of design lead to consideration of regulatory approval requirements and legal liability issues.

**ENGRI 1200 Introduction to Nanoscience and Nanoengineering (also AEP 1200)**

Fall, spring. 3 credits.

Lecture/laboratory course designed to introduce first-year students to some of the ideas and concepts of nanoscience and nanotechnology. Topics include nanoscience and nanotechnology—what they are and why they are of interest; atoms and molecules; the solid state; surfaces; behavior of light and material particles when confined to nanoscale dimensions; scanning tunneling microscopy (STM), atomic force microscopy (AFM), microelectromechanical systems (MEMS) design; basic micromachining and chemical synthesis methods, i.e., "top-down" and "bottom-up" approaches to nanofabrication; how to manipulate structures on the nanoscale; physical laws and limits they place on the nanoworld; some far-out ideas. In the laboratory, students use an AFM to record atomic resolution images, use a MEMS computer-aided design software package to model the entire manufacturing sequence of a simple MEMS device, examine the simulated behavior of the device and compare it with real behavior, construct a simple STM and learn through hands on experience the basic workings of the device.

**ENGRI 1220 Earthquake! (also EAS 1220)**

Spring. 3 credits. L. Brown.

Explores the science of natural hazards and strategic resources. Covers techniques for locating and characterizing earthquakes, and assesses the damage they cause; methods of using sound waves to image the earth's interior to search for strategic materials; and the historical importance of such resources. Includes seismic experiments on campus to probe for groundwater, the new critical environmental resource.

**ENGRI 1260 Introduction to Signals and Telecommunications**

Spring. 3 credits.

Introduces the concepts that underlie wired and wireless communication systems. Students achieve a rudimentary understanding of basic ideas such as coding and data compression; frequency content, bandwidth, and filtering; sampling and reconstruction; and time- and frequency-division multiplexing. Discussions of practical applications focus on areas such as the public switched telephone network, ISDN, ATM, and TCP/IP. Students also develop an appreciation for the historical development of the field. The course includes both lectures and laboratory demonstrations.

**ENGRI 1270 Introduction to Entrepreneurship and Enterprise Engineering (also MAE 1270)**

Spring. 3 credits. Open to all Cornell students regardless of major. Prerequisite: none.

A solid introduction to the entrepreneurial process to students in engineering. The main objective is to identify and to begin to develop skills in the engineering work that occurs in high-growth, high-tech ventures. Basic engineering management issues, including the entrepreneurial perspective, opportunity recognition and evaluation, and gathering and managing resources are covered. Technical topics such as the engineering design process, product realization, and technology forecasting are discussed.

**ENGRI 1310 Introduction to Biomedical Engineering (also BME 1310)**

Spring. 3 credits. Prerequisite: freshman or sophomore standing. C. B. Schaffer and S. D. Archer.

Modern biology and medicine is undergoing a revolution as quantitative principles of measurement, analysis, and design are introduced to help solve a variety of scientific and medical problems. This course will provide an introduction to the study of biological systems with a quantitative perspective from the molecular to the cellular to the organism scale, as well as to the design of practical devices for studying biological systems and treating disease. Collaborative work will be a key element in all aspects of the course, from the lectures and labs, to the assignments and term project.

**ENGRI 1610 Computing in the Arts (also CIS/CS 1610, DANCE 1540, FILM 1750, MUSIC 1465, PSYCH 1650)**

Fall. 3 credits. Complements ART 1701+ and MUSIC 1421+. S–U or letter grades.

For description, see CS 1610 in the CIS section.

**ENGRI 1620 Visual Imaging in the Electronic Age (also ART 1700, CIS/CS 1620)**

Fall. 3 credits. S–U or letter grades. Staff.

For description, see ART 1700.

# APPLIED AND ENGINEERING PHYSICS

F. W. Wise, director; L. Pollack, director of undergraduate studies; C. Xu, director of graduate studies; D. Muller, M.Eng. coordinator; M. Lindau, Co-op coordinator; J. D. Brock, R. A. Buhrman, T. A. Cool, H. G. Craighead, A. L. Gaeta, V. O. Kostroun, M. Lindau, R. V. E. Lovelace, D. Muller, L. Pollack, J. Silcox, W. W. Webb, F. W. Wise, C. Xu. Adjunct faculty: D. H. Bilderback, Q. Hao, S. Heinekamp. Senior research associate: E. J. Kirkland. Lecturer: L. Wickham

**AEP 1100 Lasers and Photonics (also ENGRI 1100)**

Fall. 3 credits.

Course in Introduction to Engineering series. For description, see ENGRI 1100.

**AEP 1200 Introduction to Nanoscience and Nanoengineering (also ENGRI 1200)**

Fall, spring. 3 credits.

Course in Introduction to Engineering series. For description, see ENGRI 1200.

**AEP 2170 Electricity and Magnetism (also PHYS 2217)**

Fall, spring. 4 credits. Prerequisites: permission of advisor and instructor; co-registration in PHYS 2216 or knowledge of special relativity at level of PHYS 1116; MATH 1920 or equivalent and co-registration in MATH 2930 or equivalent. Staff.

Intended for students who have done well in PHYS 1112 or 1116 (or equivalent) and mathematics and who desire a more analytic treatment than that of PHYS 2213. At the level of *Electricity and Magnetism* by Purcell. Recommended for prospective engineering physics majors. Placement quiz may be given early in semester, permitting students who find material too abstract or analytical to transfer into PHYS 2213 without difficulty.

**AEP 2520 The Physics of Life (also ENGRD 2520)**

Fall. Prerequisites: MATH 1920, CHEM 2070 or 2090, and co-registration in or completion of PHYS 2213. L. Pollack.

For description, see ENGRD 2520.

**AEP 2640 Computer-Instrumentation Design (also ENGRD 2640)**

Fall, spring. 3 credits. Prerequisites: seniors by permission of instructor; CS 1110. 1 lec, 1 lab.

For description, see ENGRD 2640.

**AEP 3210 Mathematical Physics I**

Fall, summer. 4 credits. Prerequisite: MATH 2940. Intended for upper-level undergraduates in physical sciences. B. Kusse.

Review of vector analysis; complex variable theory, Cauchy-Rieman conditions, complex Taylor and Laurent series, Cauchy integral formula and residue techniques, conformal mapping; Fourier Series; Fourier and Laplace transforms; ordinary differential equations; separation of variables. Texts: *Mathematical Methods for Physicists* by Arfken and *Mathematical Physics* by Butkov.

**AEP 3220 Mathematical Physics II**

Spring. 4 credits. Prerequisite: AEP 3210. Second of two-course sequence in mathematical physics intended for upper-level undergraduates in physical sciences. B. Kusse.

Topics include partial differential equations, Bessel functions, spherical harmonics, separation of variables, wave and diffusion equations, Laplace, Helmholtz, and Poisson's Equations, transform techniques, Green's functions; integral equations, Fredholm equations, kernals; complex variables, theory, branch points and cuts, Riemann sheets, method of steepest descent; tensors, contravariant, and covariant representations; group theory, matrix representations, class and character. Texts: *Mathematical Methods for Physicists* by Arfken and *Mathematical Physics* by Butkov.

**AEP 3240 Maple Supplement to Mathematical Physics 321 and 322**

Spring. 1 credit. R. V. E. Lovelace.

A broad introduction to Maple in applications to problems of mathematical physics similar to those covered in AEP 3210 and 3220. Uses Maple to solve differential equations—both linear and nonlinear. Makes extensive use of plotting capabilities of Maple. Also covers matrices, complex functions, Laplace and Fourier transforms (and FFTs), and group theory. Gives an introduction to LaTex.

**AEP 3300 Modern Experimental Optics (also PHYS 3300)**

Fall. 4 credits. Limited enrollment. Prerequisite: PHYS 2214 or equivalent. E. Bodenschatz.

Practical laboratory course in basic and modern optics. The various projects cover a wide range of topics from geometrical optics to classical wave properties such as interference, diffraction, and polarization. Each experimental setup is equipped with standard, off-the-shelf optics and opto-mechanical components to provide the students with hands-on experience in practical laboratory techniques currently employed in physics, chemistry, biology, and engineering. Students are also introduced to digital imaging and image processing techniques.

**AEP 3330 Mechanics of Particles and Solid Bodies**

Fall, summer. 4 credits. Prerequisites: PHYS 1112 or 1116 and co-registration in AEP 3210 or equivalent or permission of instructor. Staff.

Covers Newton's mechanics; constants of the motion; many-body systems; linear oscillations; variational calculus; Lagrangian and Hamiltonian formalism for generalized coordinates; non-inertial reference systems; central-force motion; motion of rigid bodies; small vibrations in multi-mass systems; nonlinear oscillations; and basic introduction to relativistic mechanics. Emphasis is on mathematical treatments, physical concepts, and applications. (At the level of *Classical Dynamics* by Marion and Thorton.)

**AEP 3550 Intermediate Electromagnetism**

Fall, beginning third week of Oct.; summer; second half of semester. 2 credits. Prerequisite: PHYS 2213 or 2217 and co-registration with AEP 3210, or permission of instructor.

Intermediate-level course on electromagnetic theory with a focus on statics. Vector calculus, electrostatics, conductors, dielectric materials, boundary conditions, solutions to Laplace's equation, and magnetostatics. Emphasis is on developing proficiency with analytical techniques and intuitive understanding of fundamental electromagnetism.

**AEP 3560 Intermediate Electrodynamics**

Spring. 4 credits. Prerequisite: AEP 3550 and co-registration with AEP 3220, or permission of instructor.

Second course in theory of electromagnetism. Magnetic materials, Faraday's law, Maxwell equations, electromagnetic waves, reflection and transmission, guided waves, and radiation.

**AEP 3610 Introductory Quantum Mechanics**

Fall, through second week of Oct.; summer, first half of semester. 2 credits. Prerequisites: PHYS 2213 or 2217 and co-registration with AEP 3210, or permission of instructor.

Introductory course on the theory of quantum mechanics. Topics include waves, Schrödinger's equation and the concept of the wavefunction, simple potentials, and the harmonic oscillator model. Emphasis is on developing an intuitive understanding of quantum mechanics.

**AEP 3620 Intermediate Quantum Mechanics**

Spring, 4 credits. Prerequisite: AEP 3610 or PHYS 3316 and co-registration with AEP 3220 or permission of instructor.

Continuation of AEP 3610 covering more advanced material in quantum mechanics. Topics include operator formalism and matrix representation, angular momentum and spin, the hydrogen atom, techniques for solving Schrödinger's equation including perturbation theory, two- and three-level systems, interaction with radiation, and identical particles.

**AEP 3630 Electronic Circuits (also PHYS 3360)**

Fall, spring. 4 credits. Prerequisites: PHYS 2208 or 2213 or permission of instructor. No previous experience with electronics assumed; however, course moves quickly through introductory topics such as basic DC circuits. Fall semester usually less crowded. 1 lec, 2 labs. Fall: E. Kirkland; spring: Staff.

Students analyze, design, build, and experimentally test circuits used in scientific and engineering instrumentation (with discrete components and integrated circuits). Analog circuits: resistors, capacitors, operational amplifiers (linear amplifiers with feedback, oscillators, comparators), filters, diodes, and transistors. Digital circuits: combinatorial (gates) and sequential (flip-flops, counters, shift registers) logic. Computer interfacing introduced and used to investigate digital to analog (DAC) and analog to digital conversion (ADC) and signal averaging.

**AEP 4230 Statistical Thermodynamics**

Fall. 4 credits. Prerequisite: introductory three-semester physics sequence, familiarity with quantum mechanics (AEP 3610 or PHYS 3316) and one year junior-level mathematics. Staff.

Quantum statistical basis for equilibrium thermodynamics, microcanonical, canonical and grand canonical ensembles, and partition functions. Classical and quantum ideal gases, paramagnetic and multiple-state systems. Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics and applications. Introduction to systems of interacting particles. At the level of *Introductory Statistical Mechanics* by Bowley and Sanchez.

**AEP 4340 Continuum Physics**

Spring. 4 credits. Prerequisites: AEP 3330 and 3560 or equivalent. Staff.

Topics: Elasticity and Fluid Mechanics: basic phenomena of elasticity, simple beams, stress and strain tensors, materials equations, equations of motion, general beam equations, waves; fluids: basic phenomena, Navier Stokes equation, scaling laws, Reynolds and Froude numbers, Poisseuille flows, Stokes drag on sphere, boundary layers, invicid and incompressible flows, potential flow, conservation laws, Bernoulli equation, vorticity and circulation, life of wings, jets, instabilities, introduction to turbulence. Projects in combination with AEP 4380 possible. At the level of *Continuum Mechanics* by Lai, Rubin, and Krempl and *Introduction to Fluid Mechanics* by Tritton.

**AEP 4380 Computational Engineering Physics**

Spring. 3 credits. Prerequisites: CS 1100 or 1112, AEP 3210, 3330, 3550, 3610, or equivalent, or permission of instructor; co-registration in 3620 permitted. Staff.

Numerical computation (e.g., derivatives, integrals, differential equations, matrices, boundary-value problems, relaxation, Monte Carlo methods) is introduced and applied to engineering physics problems that cannot be solved analytically (e.g., three-body problem, electrostatic fields, quantum energy levels). Computer programming required (in C or optionally C++, FORTRAN, or Pascal). Some prior exposure to programming assumed but no previous experience with C assumed.

**AEP 4440 Quantum and Nonlinear Optics**

Spring. 4 credits. Prerequisites: AEP 3560, 3620, or equivalent. Staff.

Introduction to the fundamentals of the interaction of laser light with matter and to optical devices based on these processes. Topics include the propagation of laser beams in bulk media and guided-wave structures, the origins of optical nonlinearities, harmonic generation, parametric amplification, self-focusing, optical switching, propagation of ultrashort pulses, solitons, four-wave mixing, optical phase conjugation, optical resonance and two-level atoms, atom cooling and trapping, multiphoton processes, spontaneous and simulated scattering, and ultra-intense laser-matter interactions.

**AEP 4500 Introductory Solid State Physics (also PHYS 4454)**

Fall. 4 credits. Highly recommended: some exposure to quantum mechanics at level of PHYS 4443, AEP 3620, or CHEM 7930. Staff.

Introduction the physics of crystalline solids. Covers crystal structures; electronic states; lattice vibrations; and metals, insulators, and semiconductors. Computer simulations of the dynamics of electrons and ions in solids. Covers optical properties, magnetism, and superconductivity as time allows. The majority of the course addresses the foundations of the subject, but time is devoted to modern and/or technologically important topics such as quantum size effects. At the level of *Introduction to Solid State Physics* by Kittel or *Solid State Physics* by Ashcroft and Mermun.

**AEP 4700 Biophysical Methods (also BIONB 4700)**

Fall. 3 credits. Prerequisites: solid knowledge of basic physics and mathematics through sophomore level. Recommended: some knowledge of cellular biology. Letter grades only.

Overview of the diversity of modern biophysical experimental techniques used in the study of biophysical systems at the cellular and molecular level. Topics include methods that examine both structure and function of biological systems, with emphasis on the applications of these methods to biological membranes. The course format includes assigned literature reviews by the students on specific biophysics topics and individual student presentations on these topics. The course is intended for students of the engineering, physics, chemistry, and biological disciplines who seek an introduction to modern biophysical experimental methods.

**AEP 4840 Introduction to Controlled Fusion: Principles and Technology (also ECE/NSE 4840, MAE 4590)**

Spring. 3 credits. On demand. Prerequisites: PHYS 1112, 2213, and 2214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students.

For description, see NSE 4840.

**AEP 4900–4910 Independent Study in Engineering Physics**

Fall, spring. Credit TBA.

Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the faculty. The study can take a number of forms; for example, design of laboratory apparatus, performance of laboratory measurements, computer simulation or software developments, theoretical design and analysis. Details TBA with respective faculty member.

**AEP 5500 Applied Solid State Physics**
Spring. 3 credits. Prerequisites: AEP 3560, 3620, 4230, 4500 or equivalent.
Directed at students who have had an introductory course in solid state physics at the level of Kittel. Concentrates on the application of the quantum mechanical theory of solid state physics to semiconductor materials, solid state electronic devices, solid state detectors and generators of electromagnetic radiation, superconducting devices and materials, the nonlinear optical properties of solids, ferromagnetic materials, nanoscale devices, and mesoscopic quantum mechanical effects. The course stresses the basic, fundamental physics underlying the applications rather than the applications themselves. At the level of *Introduction to Applied Solid State Physics* by Dalven.

**AEP 5710 Biophysical Methods Advanced Laboratory**
Spring, first three weeks of Jan. or TBA during spring semester. 3 credits. Prerequisite: AEP 4700 highly recommended but qualified students who have not taken AEP 4700 also accepted. Letter or S–U grades. M. Lindau.
Offered to students in the engineering, physics, chemistry and biological disciplines who are interested in research at the interface between physical sciences/engineering and life sciences. In groups of two, participants perform five experiments in research laboratories on state-of-the-art equipment. Lab training sessions are arranged individually in January and throughout the spring semester. Typically each experiment is two days in the lab plus one day for analysis and report writing. The course is intended for students who seek hands-on introduction to modern biophysical experimental methods.

**AEP 6070 Advanced Plasma Physics (also ECE 5820)**
Spring. On demand. 4 credits. Prerequisites: ECE 5810 and AEP 6060.
For description, see ECE 5820.

**AEP 6330 Nuclear Reactor Engineering (also NSE 6330)**
Fall. 4 credits. Prerequisite: introductory course in nuclear engineering. Offered on demand. K. B. Cady.
For description, see NSE 6330.

**AEP 6610 Nanocharacterization**
Fall. 3 credits. Prerequisites: Fourier transforms, basic electromagnetism, and undergraduate quantum mechanics or chemistry. Undergraduates should consult with instructor before enrolling.
Graduate-level introduction to the tools used to image and probe optical, electronic, chemical, and mechanical properties at the nanoscale and below. Discussion centers on the physics of the interaction processes used for characterization, quantification, and interpretation of the collected signals, common artifacts, the engineering trade-offs made in constructing the actual instruments, and the fundamental detection limits for each method. Topics include the interaction of electrons, ions, and photons with materials; scanned probe and force microscopy; scanning and transmission electron microscopy; x-ray microanalysis; electron energy loss spectroscopy; and a brief survey of non-imaging methods such as RBS, XPS, and SIMS.

**AEP 6620 Micro/Nano-fabrication and Processing**
Spring. 3 credits.
Introduction to the fundamentals of micro- and nano-fabricating and patterning thin-film materials and surfaces, with emphasis on electronic and optical materials, micromechanics, and other applications. Vacuum and plasma thin-film deposition processes. Photon, electron, X-ray, and ion-beam lithography. Techniques for pattern replication by plasma and ion processes. Emphasis is on understanding the physics and materials science that define and limit the various processes. At the level of Brodie and Muray.

**AEP 6630 Nanobiotechnology (also BIOG 6630, MSE 5630)**
Spring. 3 credits. Letter grades only.
Upper-level undergraduate and graduate-level course that covers the basics of biology and the principles and practice of microfabrication techniques. The course focuses on applications in biomedical and biological research. A team design project that stresses interdisciplinary communication and problem solving is one of the course requirements. The course meets twice weekly with 75-minute classes. All lectures are teleconferenced to NBTC associate institutes.

**AEP 7110 Principles of Diffraction (also MSE 6710)**
Fall. 3 credits. Letter grades only. J. D. Brock.
Graduate-level introduction to diffraction/scattering phenomena in the context of solid-state and soft condensed-matter systems. The primary topic is using the scattering and absorption of neutron, electron, and X-ray beams to study physical systems. Particular emphasis is placed on issues related to synchrotron X-ray sources. Specific topics that are covered in the course include: elastic and inelastic scattering; diffraction from two- and three-dimensional periodic lattices; the Fourier representation of scattering centers and the effects of thermal vibrations and disorder; diffraction, reflectivity, or scattering from surface layers; diffraction or scattering from gases and amorphous materials; small angle scattering; X-ray absorption spectroscopy; resonant (e.g., magnetic) scattering; novel techniques using coherent X-ray beams; and a survey of dynamical diffraction from perfect and imperfect lattices.

**AEP 7510 M.Eng. Project**
Fall, spring. 6–12 credits TBA. Requirement for M.Eng. (engineering physics) students.
Independent study under the direction of a member of the university faculty. Students participate in an independent research project through work on a special problem related to their field of interest. A formal and complete research report is required.

**AEP 7530 Special Topics Seminar in Applied Physics**
Fall. 1 credit. Requirement for M.Eng. (engineering physics) students; recommended for seniors in engineering physics. Prerequisite: undergraduate physics.
Special topics in applied science, with focus on areas of applied physics and engineering that are of current interest. Subjects chosen are researched in the library and presented in a seminar format by the students. Effort is made to integrate the subjects within selected subject areas such as atomic, biological, computational, optical, plasma, and solid-state physics, or microfabrication technology, as suggested by the students and coordinated by the instructor.

**[AEP 7810 Advanced Plasma Physics I: Cosmic Plasma Physics]**

**AEP 7820 Advanced Plasma Physics (also ECE 6820)**
Spring. 3 credits. Prerequisite: ECE 5810. C. E. Seyler.
For description, see ECE 6820.

## BIOLOGICAL AND ENVIRONMENTAL ENGINEERING

D. J. Aneshansley, chair; B. A. Ahner, assoc. chair; L. T. Angenent, L. D. Albright, A. J. Baeumner, J. A. Bartsch, A. K. Datta, K. G. Gebremedhin, D. A. Haith, P. G. Hess, J. B. Hunter, L. H. Irwin, D. Luo, J. C. March, J.-Y. Parlange, N. R. Scott, R. M. Spanswick, T. S. Steenhuis, M. B. Timmons, L. P. Walker, M. F. Walter, M. T. Walter. Lecturers: C. L. Anderson, T. J. Cook, L. D. Geohring

For complete course descriptions, see “Biological and Environmental Engineering” under “College of Agriculture and Life Sciences” or visit the department web site, www.bee.cornell.edu.

**BEE 1130 Introduction to Metal Fabrication Techniques**
Spring. 3 credits. Limited to 20 students per lab.

**BEE 1140 Introduction to Wood Construction**
Fall. 3 credits. Limited to 16 students per lab.

**BEE 1150 Advanced Metal Fabrication Techniques**
Spring. 1–2 credits. Prerequisite: BEE 1130 or permission of instructor.

**BEE 1200 The BEE Experience**
Spring. 1 credit. Requirement for CALS BEE freshmen. Not required for students who have completed ENGRG 1050. Prerequisite: BEE majors or permission of instructor.

**BEE 1510 Introduction to Computer Programming**
Fall. 4 credits. Limited to 18 students per lab and rec. Pre- or corequisite: MATH 1910 or equivalent. No previous programming experience assumed.

**BEE 2220 Bioengineering Thermodynamics and Kinetics**
Spring. 3 credits. Prerequisites: MATH 1920, BIOG 1110, PHYS 2213, and chemistry course completed or concurrent.

**BEE 2510 Engineering for a Sustainable Society (also ENGRD 2510)**
Fall. 3 credits. Pre- or corequisite: MATH 2930.

**BEE 2600 Principles of Biological Engineering (also ENGRD 2600)**
Fall. 3 credits. Pre- or corequisite: MATH 2930.

**BEE 3050 Principles of Navigation (also NAVS 3050)**
Spring. 4 credits. Three classes each week (lec-rec-project work).

**BEE 3299 Sustainable Development: A Web-Based Course**
Spring, summer. 3 credits. Prerequisite: at least sophomore standing. S–U or letter grades.

**BEE 3310 Bio-Fluid Mechanics**
Fall. 4 credits. Prerequisites: ENGRD 2020 and engineering math sequence.

**BEE 3500 Biological and Environmental Transport Processes**
Fall. 3 credits. Pre- or corequisites: MATH 2930 and fluid mechanics course.

**BEE 3600 Molecular and Cellular Bioengineering (also BME 3600)**
Spring. 3 credits. Prerequisites: BEE 2600, biochemistry, linear algebra, ordinary differential equations, or permission of instructor.

**BEE 3650 Properties of Biological Materials**
Spring. 3 credits. Pre- or corequisite: ENGRD 2020.

**[BEE 3680 Biotechnology Applications: Animal Bioreactors**
Fall. 3 credits. Prerequisite: biochemistry course or permission of instructor. Offered alternate years; next offered 2009–2010.]

**BEE 3710 Physical Hydrology for Ecosystems**
Spring. 3 credits. Prerequisite: MATH 1920 or permission of instructor. Offered alternate years.

**BEE 4010 Renewable Energy Systems**
Spring. 3 credits. Prerequisite: college physics.

**[BEE 4270 Water Sampling and Measurement**
Fall. 3 credits. Prerequisites: fluids or hydrology course and MATH 1910. Next offered 2009–2010.]

**BEE 4350 Principles of Aquaculture**
Spring. 3 credits. Prerequisite: at least junior standing.

**BEE 4500 Bioinstrumentation**
Spring. 4 credits. Prerequisites: MATH 2940, introductory computing, two semesters of physics, statistics, or permission of instructor.

**BEE 4530 Computer-Aided Engineering: Applications to Biomedical Processes (also MAE 4530)**
Spring. 3 credits. Prerequisite: heat and mass transfer course (BEE 3500 or equivalent).

**[BEE 4540 Physiological Engineering**
Fall. 3 credits. Prerequisites: differential equations, two semesters of physics, introductory biology, statistics. Next offered 2009–2010.]

**BEE 4590 Biosensors and Bioanalytical Techniques**
Fall. 3 credits. Prerequisite: biochemistry course or permission of instructor.

**BEE 4600 Deterministic and Stochastic Modeling in Biological Engineering**
Fall. 3 credits. Prerequisites: MATH 2930, MATH 2940, BEE 3500 or equivalent, Mass and Energy Balances, or permission of instructor.

**BEE 4640 Bioseparation Processes**
Fall. 3 credits. Prerequisites: introductory biochemistry and physics, MATH 1920, BEE 2600 or equivalent, or permission of instructor. Offered alternate years.

**[BEE 4710 Introduction to Groundwater (also EAS 4710)**
Spring. 3 credits. Prerequisites: MATH 2930, fluid mechanics or hydrology course. S–U or letter grades. Next offered 2009–2010.]

**BEE 4730 Watershed Engineering**
Fall. 3 credits. Prerequisite: fluid mechanics or hydrology course.

**BEE 4740 Water and Landscape Engineering Applications**
Spring. 3 credits. Prerequisite: fluids or hydrology course or permission of instructor.

**BEE 4750 Environmental Systems Analysis**
Fall. 3 credits. Prerequisites: computer programming course and one year of calculus.

**BEE 4760 Solid Waste Engineering**
Spring. 3 credits. Prerequisites: one semester of physics and chemistry.

**[BEE 4780 Ecological Engineering**
Spring. 3 credits. Prerequisite: junior-level environmental quality engineering course or equivalent. Next offered 2009–2010.]

**BEE 4800 Introduction to Atmospheric Chemistry (also EAS 4800)**
Fall. 3 credits. Prerequisites: CHEM 2090, MATH 1920, PHYS 1112 or equivalent, or permission of instructor. S–U or letter grades.

**BEE 4810 LRFD–Based Engineering of Wood Structures (also CEE 4810)**
Spring. 3 credits. Prerequisite: ENGRD 2020.

**BEE 4840 Metabolic Engineering**
Spring. 3 credits. Prerequisite: biochemistry course or permission of instructor.

**BEE 4870 Sustainable Energy Systems**
Fall. 3 credits. Prerequisites: BEE 3500 and thermodynamics course.

**BEE 4890 Entrepreneurial Management for Engineers**
Spring. 4 credits. Prerequisites: ENGRD 2700 or CEE 3040 or equivalent highly recommended; junior standing.

**BEE 4900 Biofuels: The Economic and Environmental Interactions (also AEM 6900)**
Spring. 2 credits. Prerequisites: senior or graduate standing, others by permission of instructor. S–U or letter grades.

**BEE 4930 Technical Writing for Engineers**
Fall. 1 credit. Corequisite: BEE 4730.

**BEE 4960 Capstone Design in Biological and Environmental Engineering**
Fall, spring. 1 credit. Corequisite: BEE 4730 or 4780, or 4810.

**BEE 4970 Individual Study in Biological and Environmental Engineering**
Fall, spring. 1–4 credits. Prerequisites: written permission of instructor and adequate ability and training for work proposed. Normally reserved for seniors in upper two-fifths of their class. Students from all colleges must register using independent study form (available in 207 Riley-Robb Hall).

**BEE 4980 Undergraduate Teaching**
Fall, spring. 1–4 credits. Prerequisite: written permission of instructor. Students from all colleges must register using independent study form (available in 207 Riley-Robb Hall).

**BEE 4990 Undergraduate Research**
Fall, spring. 1–4 credits. Prerequisites: written permission of instructor; adequate training for work proposed. Normally reserved for seniors in upper two-fifths of their class. Students from all colleges must register using independent study form (available in 207 Riley-Robb Hall).

**BEE 4991 Honors Research**
Fall, spring. 1–6 credits. Prerequisite: enrollment in BEE Honors Research Program.

**BEE 5010 Bioengineering Seminar (also BME 5010)**
Fall, spring. 1 credit. Prerequisite: junior, senior, or graduate standing. S–U grades only.

**BEE 5330 Engineering Professionalism**
Spring. 1–2 credits. Prerequisite: graduate student with accredited engineering degree or senior who will be graduate with accredited engineering degree. Must register to take Fundamentals of Engineering Exam. Lec only for first 10 weeks of semester. S–U or letter grades.

**BEE 5900 M.P.S. Project**
Fall, spring. 1–6 credits. Requirement for all M.P.S. candidates in field.

**BEE 5950 Master of Engineering Design Project**
Fall, spring. 3–6 credits. Prerequisite: admission to M.Eng. degree program.

**BEE 6430 Veterinary Perspectives on Pathogen Control in Animal Manure (also VTMED/BIOMI 6430)**
Spring. Eight weeks. 2 credits. Prerequisites: limited to third- and fourth-year veterinary students.

**[BEE 6470 Water Transport in Plants (also BIOPL 6510)**
Fall. 2 credits. Offered alternate years; next offered 2009–2010.]

**BEE 6490 Solute Transport in Plants (also BIOPL 6490)**
Fall. 3 credits. Offered alternate years.

**[BEE 6510 Bioremediation: Engineering Organisms to Clean Up the Environment**
Spring. 3 credits. Prerequisite: BIOMI 2900 or BIOBM 3310 or permission of instructor. Next offered 2009–2010.]

**[BEE 6550 Thermodynamics and Its Applications**
Fall. 3 credits. Prerequisite: MATH 2930 or equivalent; for undergraduates, permission of instructor. Offered alternate years; next offered 2009–2010.]

**BEE 6590 Biosensors and Bioanalytical Techniques**
Fall. 3 credits. Prerequisites: biochemistry course and permission of instructor.

**BEE 6710 Analysis of the Flow of Water and Chemicals in Soils**
Fall. 3 credits. Prerequisites: four calculus courses and fluid mechanics course; for undergraduates, permission of instructor. Offered alternate years.

**BEE 6720 Drainage**
Spring. 4 credits. Prerequisite: BEE 4710 or 4730. Offered alternate years.

**[BEE 6740 Ecohydrology**
Spring. 3 credits. Prerequisite: ecohydrology or hydrology course. Offered alternate years; next offered 2009–2010.]

**BEE 6870 The Science and Engineering Challenges to the Development of Sustainable Bio-Based Industries**
Fall. 1 credit. Prerequisite: graduate standing. S–U grades only.

**BEE 6970 Graduate Individual Study in Biological and Environmental Engineering**
Fall, spring. 1–6 credits. Prerequisite: permission of instructor. S–U or letter grades.

**BEE 7000 Orientation to Graduate Study**
Fall. 1 credit. Prerequisite: newly joining graduate students in BEE. S–U grades only.

**BEE 7010 BEE Seminar Series**
Spring. 1 credit. S–U or letter grades.

**BEE 7540 Water and Culture in the Mediterranean: A Crisis**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. S–U or letter grades.

**[BEE 7600 Nucleic Acid Engineering (also BME 7600)**
Spring. 2 credits. Prerequisite: graduate standing; seniors by permission of instructor. S–U or letter grades. Next offered 2009–2010.]

**BEE 7710 Soil and Water Engineering Seminar**
Fall, spring. 1 credit. Prerequisite: graduate standing or permission of instructor. S–U or letter grades.

**[BEE 7870 Industrial Ecology of Agriculturally Based Bioindustries**
Spring. 3 credits. Prerequisites: one year calculus, MATLAB, BEE 6870, graduate standing. Offered alternate years; next offered 2009–2010.]

**BEE 7880 Biomass Conversion of Energy and Chemicals**
Spring. 3 credits. Prerequisites: one year college calculus and chemistry; minimum of one course in thermodynamics and computer programming. Offered alternate years.

**BEE 8900 Master's-Level Thesis Research**
Fall, spring. 1–15 credits. Prerequisite: permission of advisor. S–U grades only.

**BEE 9900 Doctoral-Level Thesis Research**
Fall, spring. 1–15 credits. Prerequisite: permission of advisor. S–U grades only.

## BIOMEDICAL ENGINEERING

M. L. Shuler, James M. and Marsha McCormick chair; L. J. Bonassar, associate chair; J. T. Butcher, P. C. Doerschuk, director of graduate studies, C. Fischbach-Teschl, M. Jin, W. L. Olbricht, D. A. Putnam, C. Reinhart-King, C. B. Schaffer, D. J. Skorton, Y. Wang, W. R. Zipfel. Senior lecturers: S. D. Archer, D. Lipson

**BME 1310 Introduction to Biomedical Engineering (also ENGRI 1310)**
Spring. 3 credits. Prerequisite: freshman or sophomore standing. C. B. Schaffer and S. D. Archer.
For description, see ENGRI 1310.

**BME 3010 Molecular Principles of Biomedical Engineering (also CHEME 4010)**
Fall. 3 credits. Prerequisite: basic biology such as BIOG 1110, BIOBM 3300, or BIOMI 2900. Lec and lab. M. Jin and S. D. Archer.
Introduction to genomics, proteomics, bioinformatics, and computational biology with an emphasis on the engineering challenges for these areas. Covers cytoskeletal and motor proteins and their relationship to nano- and micro-machines and nanobiotechnology. Existing and emerging technologies and instrumentation critical to molecular-level analysis in biomedical engineering.

**BME 3020 Cellular Principles of Biomedical Engineering (also CHEME 4020)**
Spring. 3 credits. Prerequisite: BME 3010 or course work in basic biology such as BIOG 1110, BIOBM 3300, or BIOMI 2900 plus mathematics through differential equations (e.g., MATH 2210 or 2940), or permission of instructor. Lec and lab. C. Fischbach-Teschl and S. D. Archer.
Integration of mammalian cell biology with engineering modeling principles, put into the context of medical pathology and disease states. Consists of three modules: (1) cell culture techniques/receptor ligand interactions, (2) cellular trafficking, and (3) signal transduction.

**[BME 3300 Introduction to Computational Neuroscience (also BIONB/PSYCH/COGST 3300)**
Fall. 3 or 4 credits; 4 credits includes lab providing additional computer simulation exercises. Limited to 25 students. Prerequisites: BIONB 2220 or permission of instructor. S–U or letter grades. Offered alternate years; next offered 2008–2009. C. Linster.
For description, see BIONB 3300.]

**BME 3600 Molecular and Cellular Bioengineering (also BEE 3600)**
Spring. 3 credits. Prerequisite: BEE 2600, biochemistry course, linear algebra, ordinary differential equations, or permission of instructor.
For description, see BEE 3600.

**BME 4010 Biomedical Engineering Analysis of Metabolic and Structural Systems (also MAE 4660)**
Fall. 3 credits. Prerequisite: basic biology course work. Highly recommended: solid mechanics and fluid mechanics courses. Lec and lab. L. J. Bonassar and S. D. Archer.
Presents the quantitative biology of the renal, respiratory, cardiovascular, and musculoskeletal systems. Includes mathematical modeling of physiological processes involving mechanics and transport in solid and fluid organs.

**BME 4020 Electrical and Chemical Physiology**
Spring. 3 credits. Prerequisite: BME 3010, 3020, or 4010 or biology background or permission of instructor. Lec and lab. D. Lipson and S. D. Archer.
Focuses on understanding how circulating agents and bioelectric activity comprises inter-organ and central nervous system communication, and control of the human body. Additional emphasis includes examining medical devices involved in the treatment of human disease.

**BME 4110 Science and Technology Approaches to Problems in Human Health**
Fall. 3 credits. Prerequisites: junior, senior, or graduate standing; sophomores by permission of instructor. C. B. Schaffer and M. G. Kaplitt.
Provides an in-depth look at diseases that impact human health along with current scientific research and engineering that is aimed at addressing these problems. Faculty from the Weill Cornell Medical College will discuss health problems they are unable to treat as well as they would like, then Cornell University and Weill faculty will discuss current research aimed at better understanding disease process, developing new treatment strategies, and improving patient outcomes. The course is particularly appropriate for students considering medical school or careers in biomedical science and engineering.

**BME 4640 Orthopaedic Tissue Mechanics (also MAE 4640)**
Spring. 3 credits. Prerequisites: ENGRD 2020 and MAE 3250 or permission of instructor. Offered alternate years.
For description, see MAE 4640.

**BME 4810 Biomedical Engineering (also CHEME 4810)**
Spring. 3 credits. Prerequisite: CHEME 3240 or equivalent or permission of instructor. W. L. Olbricht.
For description, see CHEME 4810.

**BME 4900 Independent Undergraduate Project in Biomedical Engineering**
Fall, spring. Variable credit.
Research or projects by an individual or a small group of undergraduates.

**BME 4910 Principles of Neurophysiology (also BIONB 4910)**
Spring. 4 credits. Limited to 20 students. Prerequisite: BIONB 2220 or written permission of instructor. S–U or letter grades for graduate students by permission of instructor. B. R. Johnson.
For description, see BIONB 4910.

**BME 5010 Bioengineering Seminar (also BEE 5010)**
Fall, spring. 1 credit. Prerequisite: junior, senior, or graduate standing. Staff.
Gives the engineer-in-training a BROAD overview of different aspects of biological and biomedical engineering including business, legal, and clinical issues. To give students a working knowledge of how abstracts are written and revised. Sessions may occasionally be held outside of scheduled times.

**BME 5020 Biomedical System Design (also ECE 5020)**
Spring. 1–4 credits. Pre- or corequisites: at least one of ECE 4250, 4760, 4530. J. C. Belina.
For description, see ECE 5020.

**BME 5390 Biomedical Materials and Devices for Human Body Repair (also FSAD 4390)**
Spring. 2–3 credits. Prerequisites: junior or senior standing; college natural science requirement (chemistry or biology). C. C. Chu.
For description, see FSAD 4390.

**BME 5500 Product Engineering and Design in Biomedical Engineering**
Fall. 3 credits. Prerequisite: graduate standing; requirement for M.Eng. students majoring in BME. D. Lipson.
A beginning to a cornerstone understanding of engineering, regulatory business, and individual issues for new medical product development. Student background and interests may be highly varied. To accommodate these varied perspectives, the initial focus of the class is on the engineering perspectives of design and development, enabling those undertaking projects (BME 5910) to have timely exposure to key enabling concepts.

**BME 5620 Biomineralization (also MSE 5620)**
Spring. 3 credits. L. Estroff.
For description, see MSE 5620.

**[BME 5650 Biomechanical Systems—Analysis and Design (also MAE 5650)]**

**BME 5700 Biophysical Methods (also BIONB/AEP 4700)**
Fall. 3 credits. Prerequisites: solid knowledge of basic physics and mathematics through sophomore level. Recommended: some knowledge of cellular biology. Letter grades only. M. Lindau.
For description, see AEP 4700.

**BME 5710 Analytical Techniques for Material Science (also MSE 5710)**
Spring. 3 credits. D. Grubb.
For description, see MSE 5710.

**BME 5780 Computer Analysis of Biomed Images (also ECE 5780)**
Spring. 4 credits. Prerequisite: permission of instructor. A. P. Reeves.
For description, see ECE 5780.

**BME 5810 Soft Tissue Biomechanics (also MAE 5680)**
Fall. 3 credits. Prerequisites: graduate standing; seniors by permission of instructor. J. T. Butcher.
Introduces concepts of biomechanics applied to understanding the material behavior of soft tissues. Topics include finite strain, nonlinearities, constitutive frameworks, and experimental methodologies. Tissues to be modeled include tendons, blood vessels, heart valves, cartilage, and engineered tissues.

**BME 5830 Cell-Biomaterials Interactions**
Spring. 3 credits. Prerequisites: BME 3010, concurrent with 3020, or permission of instructor. C. Reinhart-King.
Biological principles underlying biomaterial design and cell adhesive behavior, incorporating biomechanical analysis across the molecular, cellular, and tissue length scales.

**[BME 5850 Current Practice in Tissue Engineering**
Spring. 3 credits. Prerequisites: BME 3010 or 4010 (or BME 3020 as corequisite). Next offered 2010. C. Fischbach-Teschl.
Covers fundamental biological principles and engineering concepts underlying the field of tissue engineering and describes specific strategies to engineer tissues for clinical use along with examples.]

**BME 5910 Design Project**
Fall, spring. 3–6 credits. Requirement for M.Eng. students majoring in BME. Students encouraged to register for two semesters as continuing course. D. Lipson and staff.
Design and economic evaluation of a biomedical engineering device or therapeutic strategy. Team projects are encouraged.

**BME 5930 Independent Design Project**
Fall and spring. Variable credit. Prerequisite: graduate standing. D. Lipson and staff.
Graduate-level nonthesis research or studies on special projects in biomedical engineering.

**BME 6180 Principles of Medical Imaging (also VTMED 6180)**
Fall. 1–3 credits. Prerequisites: 3-credit enrollment requires functional knowledge and skills of linear algebra, calculus, Fourier transformation, and calculus-based physics. Y. Wang and N. Dykes.
One-credit version requires attendance the first five weeks of lectures on nonmathematical description of imaging principles and field trips to Cornell University Hospital for Animals (CUHA) to see imaging in clinical practice. Three-credit version requires attendance for the entire semester. The later part of the lectures focus on mathematical description of imaging principles. The formulations of spatial encoding and image contrasts are presented for all major medical imaging modalities: x-ray, CT, MR, SPECT/PET, US. The inverse problem between detected signal and image source will be discussed and the concepts of image resolution, SNR, and scan time will be illustrated analytically and quantitatively for all modalities.

**BME 6260 Biomedical Optics, Imaging, and Spectroscopy**
Spring. 3 credits. Prerequisites: introductory physics, calculus and biology. W. R. Zipfel.
Fundamentals of optical systems design, application and analysis concepts used in biological imaging and biomedical optics. The course covers the theory and application of light sources, lenses, mirrors, dispersion elements, optical fibers, detectors and tissue optics; optical systems analysis concepts such as resolution, optical transfer functions, deconvolution and interference, all in relation to biomedical microscopy, spectroscopy and bioanalytical techniques.

**[BME 6310 Engineering Principles for Drug Delivery (also CHEME 6310)]**

**BME 6410 Biomedical Engineering Analysis of Proteins for Medicine**
Spring. 3 credits. Prerequisites: graduate standing and background in biology and chemistry. M. Jin.
Protein engineering principles applied to developing molecules for biotherapeutics and biophysical studies. Course topics include general overview on biochemistry, molecular understanding of proteins in cell signaling, physiology, and pathophysiology, and reviews on modern instrumentations for biophysical studies of proteins. Includes hands-on experience with computers and algorithms for structure inspection and rational design of proteins for medicine.

**BME 6501 Natural Engineering: Developmental Biology Paradigms for Regenerative Medicine**
Spring. 1–3 credits. Prerequisite: graduate student standing. J. T. Butcher.
The course will be in two modules. The first module, a 1-credit course, will cover the embryonic development and fetal maturation of several major organ systems, including lung, heart, vascular, and bone from an engineer's perspective (evolutionary conservation, major signaling pathways involved, etc). The second module, a 2-credit course, will build upon the first module by highlighting engineering approaches to study developmental biology (systems biology, mechanical testing, micro-environmental control, genetic manipulation, tissue engineering, etc.). We will also identify relationships between developmental biology and postnatal disease, as well as explore developmental biology–based approaches for regenerative medicine (directed stem cell differentiation, mechanical conditioning, matrix based differentiation, etc.). Material will be drawn largely from primary literature. Students will have regular manuscript reviews, two midterms, and a final project analyzing the natural engineering of a different organ system.

**BME 6640 Mechanics of Bone (also MAE 6640)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years.
For description, see MAE 6640.

**BME 6650 Principles of Tissue Engineering (also MAE/MSE 6650)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. L. Bonassar.
Covers introductory concepts in tissue engineering, including polymeric biomaterials used for scaffolds, mechanisms of cell-biomaterial interaction, biocompatibility and foreign body response, cell engineering, and tissue biomechanics. This knowledge is applied to engineering of several body systems, including the musculoskeletal system, cardiovascular tissues, the nervous system, and artificial organs. These topics are discussed in the context of scale-up, manufacturing, and regulatory issues.

**BME 6670 Nanobiotechnology (also AEP/BIOG 6630, MSE 5630)**
Fall. 3 credits. Letter grades only. M. L. Shuler and H. C. Hoch.
Upper-level undergraduate and graduate-level course that covers the basics of biology and

the principles and practice of microfabrication techniques. Course lectures are largely from guest faculty with expertise in the presented topic areas. The course focuses on applications in biomedical and biological research. A team design project that stresses interdisciplinary communication and problem solving is one of the course requirements. The course meets twice weekly with 75-minute classes. All lectures are teleconferenced to NBTC associate institutes.

**BME 7030 Graduate Student Teaching Experience**
Fall, spring. Variable credit. S–U or letter grades. Staff.
Guided individual experience in laboratory instruction and/or lectures/recitation instruction. Provides a preparatory teaching experience for graduate students considering an academic career.

**BME 7110 Fundamentals of Biomedical Engineering Research I**
Fall. 3 credits. Prerequisite: BME M.S./Ph.D. graduate students. W. R. Zipfel and staff.
First part of a two-semester sequence that introduces students to a variety of subjects in biomedical engineering including nanobiotechnology, biomechanics, systems and computational biology, biomaterials, tissue engineering, statistics, and experimental design. The course also covers associated subjects including professional development, ethics, writing a scientific paper, authorship issues, patents, technology transfer, conflicts of interest, and preparing a research proposal. The course is a combination of lectures and discussions, with students taking an active role in the instruction.

**BME 7120 Fundamentals of Biomedical Engineering Research II**
Spring. 3 credits. Prerequisite: BME 7110 or permission of instructor. W. L. Olbricht and staff.
Continuation of BME 7110.

**BME 7160 Immersion Experience in Medical Research and Clinical Practice**
Fall and spring. 6 credits. Prerequisite: Ph.D. students in BME. L. J. Bonassar and Y. Wang.
Seven-week immersion at Weill Medical College. Students participate in lectures, rounds, and seminars; observe surgeries; and solve medical problems presented by the staff.

**BME 7310 Advanced Biomedical Engineering Analysis of Biological Systems**
Fall. 3 credits. Prerequisite: graduate standing; priority given to M.S./Ph.D. and M.Eng. students majoring in BME. P. C. Doerschuk.
Covers the fundamentals of quantitative analysis of biological systems. Illustrates analytical methods applicable to a variety of biological systems, ranging from molecular to cellular to organ to application of whole-body systems.

**[BME 7600 Nucleic Acid Engineering (also BEE 7600)**
Spring. 2 credits. Prerequisite: graduate standing; BEE 3600 or permission of instructor. Next offered 2010. D. Luo.
For description, see BEE 7600.]

**BME 7900 Biomedical Engineering Seminar**
Fall, spring. 1 credit. Prerequisite: graduate standing. M. L. Shuler.
Research-based seminars. May meet with other seminar series as appropriate.

**BME 8999 M.S. Thesis Research**
Fall, spring. Variable credit.
Thesis research for the M.S. degree in BME.

**BME 9999 Ph.D. Thesis Research**
Fall, spring. Variable credit.
Thesis research for the Ph.D. degree in BME.

## CHEMICAL AND BIOMOLECULAR ENGINEERING

P. Clancy, director; A. B. Anton, L. A. Archer, A. M. Center, C. Cohen, S. Daniel, M. P. DeLisa, T. M. Duncan, J. R. Engstrom, F. A. Escobedo, T. Hanrath, A. J. Hunter, Y. L. Joo, D. L. Koch, W. L. Olbricht, D. A. Putnam, M. L. Shuler, P. H. Steen, A. D. Stroock, J. D. Varner

**CHEME 1120 Introduction to Chemical Engineering (also ENGRI 1120)**
Fall. 3 credits. Prerequisite: freshman standing. T. M. Duncan.
Course in the Introduction to Engineering series. For description, see ENGRI 1120.

**CHEME 2190 Mass and Energy Balances (also ENGRD 2190)**
Fall. 3 credits. Corequisite: physical chemistry course or permission of instructor. S. Daniel.
For description, see ENGRD 2190.

**[CHEME 2880 Biomolecular Engineering: Fundamentals and Applications]**

**CHEME 3010 Nonresident Lectures**
Spring. 1 credit. P. Clancy.
Lecturers from industry and from selected departments of the university provide information to assist students in their post-graduate plans.

**CHEME 3130 Chemical Engineering Thermodynamics**
Fall. 3 credits. Prerequisite: physical chemistry II. T. Hanrath.
Studies the first and second laws and their consequences for chemical systems. Covers thermodynamic properties of pure fluids, solids, and mixtures; phase and chemical reaction equilibrium; heat effects in batch and flow processes; and power cycles and refrigeration.

**CHEME 3230 Fluid Mechanics**
Spring. 3 credits. Prerequisites: CHEME 2190 and engineering mathematics sequence. L. A. Archer.
Fundamentals of fluid mechanics. Macroscopic and microscopic balances. Applications to problems involving viscous flow.

**CHEME 3240 Heat and Mass Transfer**
Fall. 3 credits. Prerequisite: CHEME 3230. A. D. Stroock.
Fundamentals of heat and mass transfer. Macroscopic and microscopic balances. Applications to problems involving conduction, convection, and diffusion.

**CHEME 3320 Analysis of Separation Processes**
Spring. 3 credits. Prerequisites: CHEME 3130 and 3240. Y. L. Joo.
Covers the analysis of separation processes involving phase equilibria and mass transfer. Topics include phase equilibria; equilibrium-based separations; rate-based separation processes (membrane separations, sorption operations); introduction to bioseparations and process simulators; choosing a separation option; and the design and synthesis of separation processes.

**CHEME 3720 Introduction to Process Dynamics and Control**
Spring. 2 credits. Prerequisites: CHEME 3130 and 3230. A. B. Anton.
Modeling and analysis of the dynamics of chemical processes, Laplace transforms, block diagrams, feedback control systems, and stability analysis.

**CHEME 3900 Chemical Kinetics and Reactor Design**
Spring. 3 credits. Prerequisites: CHEME 3130 and 3230. T. M. Duncan.
Study of chemical reaction kinetics and principles of reactor design for chemical processes.

**CHEME 4010 Molecular Principles of Biomedical Engineering (also BME 3010)**
Fall. 3 credits. Prerequisite: BIOG 1110 or BIOBM 3300. M. Jin.
For description, see BME 3010.

**CHEME 4020 Cellular Principles of Biomedical Engineering (also BME 3020)**
Spring. 3 credits. Staff.
For description, see BME 3020.

**CHEME 4130 Introduction to Nuclear Science and Engineering (also AEP/ECE/MAE/NSE/TAM 4130)**
Fall. 3 credits. B. Cady.
For description, see TAM 4130

**CHEME 4320 Chemical Engineering Laboratory**
Fall. 4 credits. Prerequisites: CHEME 3230, 3240, 3320, and 3900. A. M. Center and staff.
Laboratory experiments in fluid dynamics, heat and mass transfer, separations, other operations. Correlation and interpretation of data. Technical report writing.

**CHEME 4620 Chemical Process Design**
Spring. 4 credits. Prerequisite: CHEME 4320. A. M. Center and staff.
Students prepare a full-scale feasibility study of a chemical process including product supply and demand forecasts, process design including reaction system design, separations scheme development, heat integration via application of pinch technology, and economic analysis of the process. Students develop presentation and teamwork skills through weekly presentations.

**CHEME 4700 Process Control Strategies**
Spring. 3 credits. A. M. Center.
Introduction to how control concepts are represented, control valve sizing and selection, process control strategies, dynamic response of process systems as it relates to control loop tuning, statistical process control, advanced process control methods both for chemical and biological processes and programmable logic controllers and distributed control systems.

**CHEME 4720 Feedback Control Systems (also ECE 4720, MAE 4780)**
Fall. 4 credits. Prerequisites: CHEME 3720, ECE 2200, MAE 3260, or permission of instructor.
For description, see MAE 4780.

**[CHEME 4800 Chemical Processing of Electronic Materials]**

**CHEME 4810 Biomedical Engineering (also BME 4810)**
Spring. 3 credits. Prerequisite: CHEME 3240 or equivalent or permission of instructor. W. L. Olbricht.
Special topics in biomedical engineering, including cell separations, blood flow, design of artificial devices and artificial organs, biomaterials, image analysis, biological transport phenomena, pharmacokinetics and drug delivery, tissue engineering, and analysis of physiological processes such as adhesion, mobility, secretion, signaling, and growth.

**CHEME 4840 Microchemical and Microfluidic Systems**
Fall. 3 credits. Prerequisite: CHEME 3900 or permission of instructor. J. R. Engstrom.
Principles of chemical kinetics, thermodynamics, and transport phenomena applied to microchemical and microfluidic systems. Applications in distributed chemical production, portable power, micromixing, separations, and chemical and biological sensing and analysis. Fabrication approaches (contrasted with microelectronics), transport phenomena at small dimensions, modeling challenges, system integration, case studies.

**CHEME 4900 Undergraduate Projects in Chemical Engineering**
Fall, spring. Variable credit.
Research or studies on special problems in chemical engineering.

**CHEME 4990 Senior Seminar**
Fall, spring. 1 credit. Prerequisite: CHEME seniors. Staff.
Students attend seminars of their selection and write one-page summaries. Eligible seminars include all listings at "Colloquia and Seminars in Physics and Related Fields," which includes the weekly seminars in, for example, Chemical and Biomolecular Engineering, Chemistry and Chemical Biology, Earth and Atmospheric Sciences, History and Ethics of Engineering, and Materials Science and Engineering.

**CHEME 5200 An Overview of Chemical Processing (module)**
Fall, spring. 1–6 credits; 1 credit per sec. Fall, first third of semester. 1 credit. Prerequisite: Chemical Engineering seniors and M.Eng. A. M. Center and Staff.
Covers how the demands of fitness for purpose and market forces shape processes in the areas of pharmaceuticals, petrochemicals, and agricultural chemicals.

**CHEME 5201 Introduction to Biomedical Engineering (module)**
Spring, first third of semester. 1 credit. W. L. Olbricht.
Meets concurrently with CHEME 4810.

**CHEME 5202 Introduction to Electronic Materials Processing (module)**
Spring, first third of semester. 1 credit. A. B. Anton.
Meets concurrently with CHEME 4800.

**CHEME 5203 Introduction to Polymer Processing (module)**
Spring, second third of semester. 1 credit. L. A. Archer.
Overview and simple quantitative analyses of several plastic processes with an emphasis on the role of rheology in polymer processing.

**CHEME 5204 Turbomachinery Applications (module)**
Fall, last third of semester. 1 credit. A. M. Center.
Introduction to pumps, compressors, steam turbines and gas turbines. How they are specified and selected for services in the chemical process industries.

**CHEME 5205 Chemical Engineering Tools and Equipment (module)**
Spring, first third of semester. 1 credit. A. M. Center.
Introduces the hardware used in chemical engineering processes and a discussion of how these mechanical devices are configured to meet their process objectives. Also includes an introduction to the evaluation techniques and trouble-shooting methods frequently used by chemical engineers.

**CHEME 5207 Introduction to Petroleum Refining (module)**
Fall, second third of semester. 1 credit. A. M. Center.
Covers the petroleum refining industry including crude oil evaluation, fuel quality, refining processes, refinery configurations, and refinery economics.

**[CHEME 5208 Renewable Resources from Agriculture-Sugarcane as a Feedstock (module)**
Spring, last third of semester. 1 credit. Next offered 2010–2011.
Maximizing the value of a renewable resource by control of inputs and final product use.]

**CHEME 5430 Biomolecular Engineering of Bioprocesses**
Fall. 3 credits. Prerequisite: CHEME 3900 or permission of instructor. No prior background in biological sciences required. M. P. DeLisa.
Discusses principles involved in using biomolecules (e.g., antibodies, enzymes, DNA) and living organisms (e.g., bacteria, yeast, tissue cultures) for engineering biological processes. Primary emphasis is on development and production of biopharmaceuticals, but biological waste treatment and medical systems are also considered.

**CHEME 5640 Design of Chemical Reactors**
Spring. 3 credits. Prerequisite: CHEME 3900 or equivalent. D. L. Koch.
Design, scale-up, and optimization of chemical reactors with allowance for heat and mass transfer and non-ideal flow patterns. Homework problems feature analysis of published data for gas-solid, gas-liquid, and three-phase reaction systems.

**CHEME 5650 Design Project**
Fall, spring. 3 or 6 credits. Requirement for Chemical Engineering M.Eng. students.
Design study and economic evaluation of a chemical processing facility, alternative methods of manufacture, raw-material preparation, food processing, waste disposal, or some other aspect of chemical processing.

**CHEME 5720 Managing New Business Development**
Fall. 3 credits. Prerequisites: graduate standing or permission of instructor. Staff.
Case study approach introducing the typical fundamental factors driving a business venture, examines how to develop implementation strategies for the venture, and teaches the project management skills necessary to successfully implement the venture.

**CHEME 5870 Energy Seminar I (also MAE 5450, ECE 5870)**
Fall. 1 credit. D. Hammer and A. J. Hunter.
For description, see ECE 5870.

**CHEME 5880 Energy Seminar II (also MAE 5460, ECE 5880)**
Fall. 1 credit. D. Hammer and A. J. Hunter

For description, see ECE 5880.

**CHEME 5999 Special Projects in Chemical Engineering**
Fall, spring. Variable credit. Prerequisite: graduate standing.
Nonthesis research or studies on special problems in chemical engineering.

**CHEME 6240 Physics of Micro- and Nanoscale Fluid Mechanics and Heat Transfer**
Fall. 3 credits. Prerequisites: undergraduate fluid or continuum mechanics (e.g., MAE 3230, CHEME 3230, AEP 4340) or permission of instructor. B. L. Kirby.
For description, see MAE 5240.

**[CHEME 6310 Engineering Principles for Drug Delivery (also BME 6310)]**

**CHEME 6400 Polymeric Materials**
Fall. 3 credits. C. Cohen.
Covers chemistry and physics of the formation and characterization of polymers; principles of fabrication.

**CHEME 6440 Aerosols and Colloids**
Fall. 3 credits. D. L. Koch.
Dynamics of micro- and nano-particles, which contain many molecules but are small enough that molecular effects are important. Topics include the formation and growth of particles; their transport, theological and phase behaviors; and their role in technologies including paints, foods, health-care products, drug delivery, composite materials and air pollution control.

**CHEME 6610 Air Pollution Control**
Spring. 3 credits. P. H. Steen.
Covers origin of air pollutants, U.S. emission standards, dispersion equations; design of equipment for removal of particulate and gaseous pollutants formed in combustion and chemical processing.

**CHEME 6640 Energy Economics**
Fall. 3 credits. A. J. Hunter.
Supply and demand for energy by sectors and regions. Operating systems and costs. Economic drivers used in simulating energy systems and consumption factors. Supply/demand projections. Interplay between energy, environment, politics, economics, and sustainability.

**CHEME 6650 Energy Engineering**
Spring. 3 credits. A. J. Hunter.
Applying thermodynamic concepts to large energy systems. Future energy scenarios. Project teams tasked with simulating complex energy systems and cost-benefit analysis.

**CHEME 7110 Advanced Chemical Engineering Thermodynamics**
Fall. 3 credits. Prerequisite: CHEM 3890–3900 and CHEME 3130 or equivalent. F. A. Escobedo.
Molecular thermodynamics of gases, lattices, and liquids, including special applications to problems in chemical engineering.

**CHEME 7130 Chemical Kinetics and Transport**
Spring. 5 credits. Prerequisite: CHEME 3900 or equivalent. C. Cohen and A. D. Stroock.
Topics include microscopic and macroscopic viewpoints; connections between phenomenological chemical kinetics and molecular reaction dynamics; reaction cross sections, potential energy surfaces, and dynamics of biomolecular collisions; molecular beam scattering; transition state theory. Unimolecular reaction dynamics; complex chemically reacting systems: reactor stability, multiple steady states, oscillations, and bifurcation; reactions in heterogeneous media; and free-radical mechanisms in combustion and pyrolysis.

**CHEME 7310 Advanced Fluid Mechanics and Heat Transfer**
Fall. 3 credits. Prerequisites: CHEME 3230–3240 or equivalent. Y. L. Joo.
Topics include derivation of conservation equations; conductive heat transfer; low Reynolds number fluid dynamics; lubrication theory; inviscid fluid dynamics; boundary layer theory; forced convection; and introduction to non-Newtonian fluid mechanics (polymeric liquids and suspensions), microfluidics, stability analysis, and turbulent flow.

**CHEME 7410 Selected Topics in Biochemical Engineering**
Fall, spring. 1 credit; may be repeated for credit. Prerequisite: permission of instructor. D. A. Putnam and M. P. DeLisa.
Discussion of current topics and research in biochemical engineering for graduate students.

**CHEME 7450 Physical Polymer Science I**
Fall. 3 credits. Corequisite: CHEME 7110 or equivalent. Offered alternate years. L. A. Archer.
Thermodynamic properties of solutions from both classical and scaling approaches. Characterization techniques of dilute solutions. Rubber elasticity; mechanical and thermodynamic properties of gels; polymer melts.

**CHEME 7510 Mathematical Methods of Chemical Engineering Analysis**
Fall. 4 credits. Staff.
Application of advanced mathematical techniques to chemical engineering analysis. Mathematical modeling, scaling, regular and singular perturbations, multiple scales, asymptotic analysis, linear and nonlinear ordinary and partial differential equations, statistics, data analysis, and curve fitting.

**CHEME 7530 Analysis of Nonlinear Systems: Stability, Bifurcation, and Continuation**
Fall. 3 credits. Prerequisite: CHEME 7510 or equivalent. Offered alternate years. P. H. Steen.
Topics include elements of stability and bifurcation theory; branch-following techniques; stability of discrete and continuous systems; and application to elasticity, reaction-diffusion, and hydrodynamic systems using software for continuation problems (AUTO).

**CHEME 7900 Seminar**
Fall, spring. 1 credit each semester. Requirement for all graduate students in field of chemical and biomolecular engineering.
General chemical engineering seminar.

**CHEME 7920 Principles and Practices of Graduate Research**
Fall. 1 credit. M. P. DeLisa and A. D. Stroock.
A colloquium/discussion group series for first-year graduate students. Topics include the culture and responsibilities of graduate research and the professional community; the mechanics of conducting research (experimental design, data analysis, serendipity in research, avoiding self-deception), documenting research (lab notebooks, computer files) and reporting research (writing a technical paper and oral presentations).

**CHEME 8999 Thesis Research**
Fall, spring. Variable credit.
Thesis research for the M.S. degree in chemical engineering.

**CHEME 9999 Thesis Research**
Fall, spring. Variable credit.
Thesis research for the Ph.D. degree in chemical engineering.

## CIVIL AND ENVIRONMENTAL ENGINEERING

J. M. Gossett, director; W. D. Philpot, associate director; J. F. Abel, W. Aquino, L. Banks-Sills, J. J. Bisogni, Jr., W. H. Brutsaert, P. G. Carr, E. A. Cowen, P. J. Diamessis, R. I. Dick, L. B. Dworsky, C. Earls, H. O. Gao, K. Gebremedhin, M. D. Grigoriu, D. A. Haith, K. C. Hover, A. R. Ingraffea, P. Koutsourelakis, F. H. Kulhawy, L. W. Lion, P. L-F. Liu, D. P. Loucks, J. R. Mbwana, W. McGuire, A. H. Meyburg, L. K. Nozick, T. D. O'Rourke, T. Peköz, P. Petrina, R. E. Richardson, R. E. Schuler, C. A. Shoemaker, J. R. Stedinger, H. E. Stewart, C. H. Trautmann, M. A. Turnquist, D. Warner, F. Wayno, M. Weber-Shirk, R. N. White

Courses in the School of Civil and Environmental Engineering are offered in three broad mission areas: Civil Infrastructure, Environment, and Engineering Systems and Management. Each area has several areas of specialization. The following are the course numbers and titles listed by specialization within each mission area. Some courses are listed in two or more mission areas because the course content is relevant to multiple areas. The school also offers a number of general courses that are not unique to one mission area. Full course descriptions follow in the subsequent section and are listed in numerical order.

### General

CEE 1130 Water Treatment Design (also ENGRI 1130) (s,3)

CEE 1160 Modern Structures (also ENGRI 1160) (f,3)

CEE 3040 Uncertainty Analysis in Engineering (f,4)

CEE 3080 Introduction to CADD (f,s,1)

CEE 3090 Special Topics in Civil and Environmental Engineering (f,s,var.)

CEE 3200 Engineering Computation (formerly CEE/ENGRD 2410) (also ENGRD 3200) (s,3)

CEE 3230 Engineering Economics and Management (also ENGRG 3230) (s,su,3)

CEE 4000 Senior Honors Thesis (f,s,var.)

CEE 4010 Undergraduate Engineering Teaching in CEE (f,s,var.)

### Civil Infrastructure

See also: CEE 1160, 3040, 3080, 3200, and 5950

***Geotechnical Engineering***

CEE 3410 Introduction to Geotechnical Engineering (s,4)

CEE 4400 Foundation Engineering (f,3)

CEE 4410 Retaining Structures and Slopes (s,3)

CEE 4440 Environmental Site and Remediation Engineering (s,3)

CEE 5041/5042 Design Project in Geotech/Structures (f,s,3)

CEE 6045 Special Topics in Geotechnical Engineering (f,s,var.)

CEE 6070 Seminar—Civil Infrastructure (f,s,1)

CEE 6400 Foundation Engineering (f,3)

CEE 6410 Retaining Structures and Slopes (s,3)

CEE 6440 Environmental Site and Remediation Engineering (s,3)

CEE 7040 Research in Geotechnical Engineering (f,s,var.)

CEE 7400 Engineering Behavior of Soils (f,3)

CEE 7410 Rock Engineering (f,3)

CEE 7440 Advanced Foundation Engineering (s,2)

CEE 7450 Soil Dynamics (s,3)

CEE 7460 Embankment Dam Engineering (s,2)

CEE 8400 Thesis—Geotechnical Engineering (f,s,var.)

***Structural Engineering***

CEE 1160 Modern Structures (f,3)

CEE 3710 Structural Modeling and Behavior (s,4)

CEE 3720 Intermediate Solid Mechanics (f,4)

CEE 4710 Fundamentals of Structural Mechanics (f,4)

CEE 4720 Introduction to the Finite Element Method (f,3)

CEE 4730 Design of Concrete Structures (f,4)

CEE 4740 Design of Steel Structures (s,4)

CEE 4750 Concrete Materials and Construction (s,3)

CEE 4770 Introduction to Composite Materials (f,3)

CEE 4780 Structural Dynamics and Earthquake Engineering (s,3)

CEE 4810 LRFD-Based Engineering of Wood Structures (s,3)

CEE 5071/5072 Design Project in Structural Engineering (f,s,3)

CEE 6070 Seminar—Civil Infrastructure (f,s,1)

CEE 6075 Special Topics in Structural Engineering (f,s,var.)

CEE 6710 Fundamentals of Structural Mechanics (f,3)

CEE 6720 Introduction to the Finite Element Method (f,3)

CEE 6730 Design of Concrete Structures (f,4)

CEE 6750 Concrete Materials and Construction (s,3)

CEE 6760 Advanced Composite Materials (s,4)

CEE 6770 Engineering Analysis (f,3)

CEE 6780 Structural Dynamics and Earthquake Engineering (s,3)

CEE 6790 Evaluation and Failure of Structures (s,3)

CEE 7070 Research in Structural Engineering (f,s,var.)

CEE 7073 Civil and Environmental Engineering Materials Project (f,s,var.)

CEE 7700 Engineering Fracture Mechanics (f,3)

CEE 7710 Stochastic Mechanics in Science and Engineering (f,3)

CEE 7720 Random Vibration (f,3)

CEE 7730 Structural Reliability (f,3)

CEE 7740 Advanced Structural Concrete (f,3)

CEE 7750 Nonlinear Finite Element Analysis (s,3)

CEE 7760 Advanced Topics in Stability (s,3)

CEE 7770 Computational Solids and Structural Mechanics (s,4.)

CEE 7790 Advanced Behavior of Metal Structures (f,4)

CEE 8700 Thesis—Structural Engineering (f,s,var.)

## Environment

See also CEE 1130, 3200, 3040, and 4920

***Environmental Engineering***

CEE 1130 Water Treatment Design (s,3)

CEE 2550 AguaClara: Sustainable Water Supply Project (f,s,var.)

CEE 3510 Environmental Quality Engineering (s,3)

CEE 4510 Microbiology for Environmental Engineering (f,3)

CEE 4520 Water Supply Engineering (f,3)

CEE 4530 Laboratory Research in Environmental Engineering (f,3)

CEE 4540 Sustainable Small-Scale Water Supplies (f,3)

CEE 4550 AguaClara: Sustainable Water Supply Project (f,s,3)

CEE 5051/5052 Design Project in Environmental Engineering (f,s,3)

CEE 6020 Seminar—Water Resources and Environmental Engineering (f,1)

CEE 6051 Seminar—Environmental Quality Engineering (s,1)

CEE 6055 Special Topics in Environmental Engineering (f,s,var.)

CEE 6530 Water Chemistry for Environmental Engineering (f,3)

CEE 6540 Aquatic Chemistry (s,3)

CEE 6550 Transport, Mixing, and Transformation in the Environment (f,3)

CEE 6560 Physical/Chemical Process (f,3)

CEE 6570 Biological Processes (s,3)

CEE 6580 Biodegradation and Biocatalysis (s,3)

CEE 7050 Research in Environmental Engineering (f,s,var.)

CEE 7360 Turbulences and Turbulent Mixing in Environmental Stratified Flows (s,3)

CEE 8500 Thesis—Environmental Engineering (f,s,var.)

***Environmental Systems***

See Engineering Systems and Management mission areas for a listing of courses in Environmental and Public Systems.

***Environmental Fluid Mechanics and Hydrology***

CEE 3310 Fluid Mechanics (f,su,4)

CEE 3320 Hydraulic Engineering (s,4)

CEE 4320 Hydrology (s,3)

CEE 4350 Coastal Engineering (s,3)

CEE 4360 Case Studies in Environmental Fluid Mechanics (s,4)

CEE 4370 Experimental Methods in Fluid Dynamics (s,3)

CEE 6020 Seminar—Water Resources and Environmental Engineering (f,1)

CEE 6030 Seminar—Hydraulics (s,1)

CEE 6035 Special Topics in Hydraulics (f,s,var.)

CEE 6290 Advanced Numerical Methods for Engineers (f,3)

CEE 6300 Computational Fluid Dynamics and Environmental Flows (s,3)

CEE 6310 Computational Simulation of Flow and Transport in the Environment (s,3)

CEE 6320 Hydrology (s,3)

CEE 6330 Flow in Porous Media and Groundwater (f,3)

CEE 6340 Boundary Layer Meteorology (f,3)

CEE 6350 Small and Finite Amplitude Water Waves (s,3)

CEE 6360 Environmental Fluid Mechanics (s,3)

CEE 6370 Experimental Methods in Fluid Dynamics (s,4)

CEE 6550 Transport, Mixing, and Transformation in the Environment (f,3)

CEE 7030 Research in Hydraulics (f,s,var.)

CEE 8300 Thesis—Fluid Mechanics and Hydrology (f,s,var.)

## Engineering Systems and Management

See also CEE 3040.

***Engineering Management***

CEE 4920 Engineers for a Sustainable World (f,3)

CEE 5900 Project Management (f,s,4)

CEE 5910/5920 Engineering Management Project (f,s,3)

CEE 5930 Engineering Management Methods (f,3)

CEE 5940 Economic Methods for Engineering and Management (f,4)

CEE 5950 Construction Planning and Operations (f,3)

CEE 5960 Management Issues in Forensic Engineering (f,3)

CEE 5970 Risk Analysis and Management (s,3)

CEE 6095 Special Topics in Engineering Management (f,s,var.)

CEE 6900 Creativity, Innovation, and Leadership (s,3)

***Environmental and Public Systems***

CEE 3230 Engineering Economics and Management (also ENGRG 3230) (s,su,3)

CEE 4650 Environment/Energy and Transportation Planning and Management (s,3)

CEE 5021/5022 Design Project in Environmental or Water Resource Systems (f,s,3)

CEE 5970 Risk Analysis and Management (s,3)

CEE 6021 Seminar—Environmental and Water Resources Systems Analysis (s,1)

CEE 6025 Special Topics in Environmental and Water Resources Systems Analysis (f,s,var.)

CEE 6200 Water Resources Systems Engineering (s,3)

CEE 6210 Stochastic Hydrology (s,3)

CEE 6230 Environmental Quality Systems Engineering (f,3)

CEE 6360 Environmental Fluid Mechanics (s,4)

CEE 6650 Environment/Energy and Transportation Planning and Management (s,3)

CEE 6930 Public Systems Modeling (f,4)

CEE 7020 Environmental and Water Resources Systems Analysis Research (f,s,var.)

CEE 8200 Thesis—Environmental and Water Resources Systems (f,s,var.)

***Remote Sensing***

CEE 4110 Remote Sensing: Resource Inventory Methods (also CSS 4110) (s,3)

CEE 6015 Special Topics—Remote Sensing (f,s,var.)

CEE 6100 Remote Sensing Fundamentals (also CSS 6100) (f,3)

CEE 6150 Digital Image Processing (s,3)

CEE 7010 Research—Remote Sensing (f,s,var.)

CEE 8100 Thesis—Remote Sensing (f,s,var.)

***Systems Engineering***

CEE 4060 Civil Infrastructure Systems (f,3)

CEE 5240 Applied Systems Engineering (also CS 5040, ECE/ORIE 5120, MAE 5910, SYSEN 5100) (f,3)

CEE 5252 Systems Architecture, Behavior, and Optimization (also CS 5050, ECE/ORIE 5130, MAE 5920, SYSEN 5200) (s,3)

CEE 5290 Heuristic Methods for Optimization (also CS/CIS 5720, ORIE 5340) (f,3–4)

CEE 6080 Seminar—Engineering Systems and Management (f,s,1)

CEE 6860 Civil Infrastructure Systems (f,3)

CEE 6930 Public Systems Modeling (f,4)

***Transportation***

CEE 3610 Introduction to Transportation Engineering (s,su,3)

CEE 4610 Urban Transportation Planning and Modeling (s,3)

CEE 4630 Transportation and Information Technology (f,3)

CEE 4640 Transportation Systems Design (s,3)

CEE 4650 Environment/Energy and Transportation Planning and Management (s,3)

CEE 5061/5062 Design Project in Transportation Engineering (f,s,3)

CEE 6060 Seminar—Transportation (f,s,1)

CEE 6065 Special Topics in Transportation (f,s,var.)

CEE 6610 Urban Transportation Planning and Modeling (s,3)

CEE 6620 Urban Transportation Network and Design and Analysis (f,3)

CEE 6630 Network Flows and Algorithms (s,3)

CEE 6650 Environment/Energy and Transportation Planning and Management (s,3)

CEE 7620 Practicum in Modeling Transportation Systems (f,3)

CEE 8600 Thesis—Transportation Engineering (f,s,var.)

**CEE 1130 Water Treatment Design (also ENGRI 1130)**

Spring. 3 credits. Students must register under ENGRI 1130. M. L. Weber-Shirk.

Course in Introduction to Engineering series. For description, see ENGRI 1130.

**CEE 1160 Modern Structures (also ENGRI 1160)**

Fall. 3 credits. Students must register under ENGRI 1160. W. Aquino.

Course in Introduction to Engineering series. For description, see ENGRI 1160.

**CEE 2550 AguaClara: Sustainable Water Supply Project**

Fall, spring. 1–3 credits. Meets with CEE 4550. M. L. Weber-Shirk.

For description, see CEE 4550.

**CEE 3040 Uncertainty Analysis in Engineering**

Fall. 4 credits. Prerequisite: first-year calculus. J. R. Stedinger.

Introduction to probability theory and statistical techniques, with examples from civil, environmental, biological, and related disciplines. Covers data presentation, commonly used probability distributions describing natural phenomena and material properties, parameter estimation, confidence intervals, hypothesis testing, simple linear regression, and nonparametric statistics. Examples include structural reliability, windspeed/flood distributions, pollutant concentrations, and models of vehicle arrivals.

**CEE 3080 Introduction to CADD**

Fall, spring. 1 credit. Prerequisites: attendance at a first meeting of one section; permission of instructor given after the first week of section meetings. No pre-enrollment allowed. Priority given to engineering students. Course begins first Mon. of each semester. Staff.

Students learn to employ computer-aided design and drafting (CADD) to construct 2D drawings and 3D models using a variety of AutoCAD techniques. VIZ, an alternative software tool for 3D modeling and 3D visualization, is also introduced. Course meets in ACCEL (second floor of the Engineering Library in Carpenter Hall) so that each student can participate on an individual computer. Grades are based on attendance, weekly exercises completed in class, and a semester project due the last week of classes.

**CEE 3090 Special Topics in Civil and Environmental Engineering**

Fall, spring. 1–6 credits. Staff.

Supervised study by individuals or groups of upper-division students on an undergraduate research project or on specialized topics not covered in regular courses.

**CEE 3200 Engineering Computation (also ENGRD 3200) (formerly ENGRD/CEE 2410)**

Spring. 3 credits. Students must register under ENGRD 3200. P. Diamessis.

For description, see ENGRD 3200.

**CEE 3230 Engineering Economics and Management (also ENGRG 3230)**

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. D. P. Loucks.

For description, see ENGRG 3230.

**CEE 3310 Fluid Mechanics**

Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Pre- or corequisite: ENGRD 2020. E. A. Cowen.

Covers hydrostatics, the basic equations of incompressible fluid flow, potential flow and dynamic pressure forces, viscous flow and shear forces, steady pipe flow, turbulence, dimensional analysis, laminar and turbulence boundary layer, flows around obstacles, and open-channel flow. Includes small-group laboratory assignments.

**[CEE 3320 Hydraulic Engineering**

Spring. 4 credits. Prerequisite: CEE 3310. Next offered 2009–2010. P. L.-F. Liu.

Application of fluid-mechanical principles to problems of engineering practice and design: hydraulic machinery, open-channels, and river engineering. Lectures supplemented by laboratory work and a design project.]

**CEE 3410 Introduction to Geotechnical Engineering**

Spring. 4 credits. Prerequisites: ENGRD 2020, CEE 3310 (or equivalent), or permission of instructor. Letter grades only. H. E. Stewart.

Fundamentals of geotechnical engineering. Topics include origins and descriptions of soil and rock as engineering materials, subsurface exploration methods, principles of effective stresses, stress distribution and ground settlements from surface loads, steady-state and time-dependent subsurface fluid flow, soil strength and failure criteria, geoenvironmental applications, and introduction to hazardous waste containment systems.

**CEE 3510 Environmental Quality Engineering**

Spring. 3 credits. J. J. Bisogni.

Introduction to engineering aspects of environmental quality control. Quality parameters, criteria, and standards for water and wastewater. Elementary analysis pertaining to the modeling of pollutant reactions in natural systems, and introduction to design of unit processes for wastewater treatment.

**CEE 3610 Introduction to Transportation Engineering**

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. A. H. Meyburg and J. Mbwana.

Introduces technological, economic, and social aspects of transportation. Emphasizes design and functioning of transportation systems and their components. Covers supply-demand interactions; system planning, design, and management; traffic flow, intersection control and network analysis; institutional and energy issues; and environmental impacts.

**CEE 3710 Structural Modeling and Behavior**

Spring. 4 credits. Prerequisite: ENGRD 2020. Corequisite: MATH 2940. Staff.

Introduction to the structural engineering enterprise including aspects of design, loads, behavior, form, modeling, mechanics, materials, analysis, and construction/manufacturing. Case studies involve different scales and various materials. Topics include analytical and finite-element computational modeling of structural systems, including cables, arches, trusses, beams, frames, and 2-D continua; deflections, strains, and stresses of structural members, systems, and 2-D continua by analytical and work/energy methods, with a focus on linear elastic behavior; the foundations of matrix structural analysis; and the application of finite-element software.

**CEE 3720 Intermediate Solid Mechanics**

Fall. 4 credits. Prerequisites: MATH 2940, CEE 3710. D. Warner.

The course presents concepts related to inelastic and nonlinear behavior of engineering materials and structures, the concept of continuum, limit and plastic analysis, and fracture. The course will be a synergy of mathematical modeling, computer simulations, and physical experimentation.

**CEE 4000 Senior Honors Thesis**

Fall, spring. 1–6 credits. For students admitted to CEE Honors Program. D. Warner.

Supervised research, study, and/or project work resulting in a written report or honors thesis.

**CEE 4010 Undergraduate Engineering Teaching in CEE**

Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.

Methods of instruction developed through discussions with faculty and by assisting with the instruction of undergraduates under the supervision of faculty.

**CEE 4060 Civil Infrastructure Systems**

Fall. 3 credits. Prerequisites: probability and statistics (CEE 3040 or equivalent), or permission of instructor. Recommended: engineering economics (CEE 3230 or equivalent) course. Letter or S–U grades. F. Vanek.

Introduction to the framing and solution of civil infrastructure problems using a systems engineering approach. Systems tools, such as optimization, life-cycle cost analysis, decision analysis, simulation, and risk analysis are examined through case studies related to civil infrastructure.

**CEE 4110 Remote Sensing: Resource Inventory Methods (also CSS 4110)**
Spring. 3 credits. Prerequisite: permission of instructor. Staff.
For description, see CSS 4110.

**CEE 4320 Hydrology**
Spring. 3 credits. Prerequisite: CEE 3310. Intended for undergraduates. Lec concurrent with CEE 6320. W. H. Brutsaert.
Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers. See description for CEE 6320.

**[CEE 4350 Coastal Engineering**
Spring. 4 credits. Prerequisite: CEE 3310. Taught based on demand; contact professor if interested in course. P. L-F. Liu.
Covers the following topics: review of hydrodynamics; small-amplitude wave theory; wave statistics; wave-structure interactions; coastal processes.]

**[CEE 4360 Case Studies in Environmental Fluid Mechanics**
Spring. 4 credits. Prerequisite: CEE 3310 or equivalent. Next offered 2009–2010. E. A. Cowen.
An introduction to fundamental fluid mechanics and transport processes of the environment through laboratory—and field—based studies (Cayuga Lake and Fall, Six-Mile, and Cascadilla Creeks) and case studies. Topics include surface and internal wave dynamics, sediment and nutrient/contaminant transport, and interfacial transfer. Lectures are based on a laboratory/field projects. Course includes a design project.]

**CEE 4370 Experimental Methods in Fluid Dynamics**
Spring. 3 credits. Pre- or corequisites: CEE 3310 or equivalent and CEE 3040 or equivalent. E. A. Cowen.
Same as CEE 6370 but no project required. For description, see CEE 6370.

**CEE 4400 Foundation Engineering**
Fall. 3 credits. Prerequisite: CEE 3410. F. H. Kulhawy.
Covers soil exploration, sampling, and in-situ testing techniques; bearing capacity, stress distribution, and settlement; design of shallow and deep foundations; compaction and site preparation; and seepage and dewatering of foundation excavations.

**CEE 4410 Retaining Structures and Slopes**
Spring. 3 credits. Prerequisite: CEE 3410. T. D. O'Rourke
Covers earth pressure theories; design of rigid, flexible, braced, tied-back, slurry wall, soil nailing, and reinforced soil structures; stability of excavation, cut, and natural slopes; and design problems stressing application of course material under field conditions of engineering practice.

**[CEE 4440 Environmental Site and Remediation Engineering**
Spring. 3 credits. Prerequisite: CEE 3410. Next offered 2009–2010. T. D. O'Rourke.
Covers the principles of hydrogeology, contaminant migration, and remediation technologies related to geotechnical and environmental engineering. Emphasizes environmental site assessment, site feasibility studies, selection of remediation procedures, and engineered landfills. Design problems are based on real projects and involve visits from practicing engineers.]

**CEE 4510 Microbiology for Environmental Engineering**
Fall. 3 credits. Prerequisites: two semesters of college chemistry; organic chemistry or permission of instructor. R. E. Richardson.
Introduction to the fundamental aspects of microbiology and biochemistry that are pertinent to environmental engineering and science. Provides an overview of the characteristics of Bacteria, Archaea, unicellular Eukaryotes (protozoa, algae, fungi), and viruses. Includes discussions of cell structure, bioenergetics and metabolism, and microbial genetics. Focus is then applied to topics pertinent to environmental engineering: pathogens; disease and immunity; environmental influences on microorganisms; roles of microbes in the carbon, nitrogen, and sulfur cycles; enzymes; bioremediation, bio-energy, molecular microbiology; and microbial ecology. This is an introductory course and is inappropriate for those who have taken BIOMI 2900 or equivalent.

**[CEE 4520 Water Supply Engineering**
Fall. 3 credits. Prerequisite: CEE 3510. Next offered 2009–2010. J. J. Bisogni.
Analysis of contemporary threats to human health from water supplies. Covers criteria and standards for potable-water quality; water-quality control theory; design of water supply facilities.]

**CEE 4530 Laboratory Research in Environmental Engineering**
Fall. 3 credits. Prerequisite: CEE 3510 or permission of instructor. J. J. Bisogni, J. M. Gossett, and A. E. Richardson.
Laboratory investigations of reactor flow characteristics; acid rain/lake chemistry; contaminated soil-site assessment and remediation; and wastewater treatment. Design of laboratory experiments, data analysis, computerized process control, and model development are emphasized.

**CEE 4540 Sustainable Small-Scale Water Supplies**
Fall. 3 credits. M. L. Weber-Shirk.
This course covers the design and analysis of small-scale drinking water supply systems. We explore the technical, economic, and social constraints that form the sustainable space—i.e., the set of viable technologies that could be adopted progressively to improve the availability and quality of water. Students work in teams to design water supply and treatment systems.

**CEE 4550 AguaClara: Sustainable Water Supply Project**
Fall, spring. 3 credits. Prerequisite or corequisite: CEE 4520, 4530, or 4540. Meets with CEE 2550. M. L. Weber-Shirk.
Student teams conduct research, build working models, design full-scale prototypes, create design algorithms, and create educational materials for technology transfer to improve drinking water quality in Honduras. For more information see aguaclara.cee.cornell.edu.

**[CEE 4610 Urban Transportation Planning and Modeling]**

**CEE 4630 Transportation and Information Technology**
Fall. 3 credits. J. R. Mbwana.
Improving the use of existing facilities transportation infrastructure has become an important objective in transportation engineering and planning. Examines the role of information technologies for effective infrastructure utilization and planning. Focuses specific attention on analyses paradigms to evaluate the benefits of information technologies in transportation systems.

**CEE 4640 Transportation Systems Design**
Spring. 3 credits. Prerequisites: CEE 3610 and CEE 4060 or permission of instructor. M. A. Turnquist.
Analysis of capacity and operational design of transportation systems, including analytical modeling techniques underlying design criteria. Evaluation of alternative designs. Management and operating policies, including congestion pricing. Facility location decisions, networks, and investment strategies.

**CEE 4650 Environment/Energy and Transportation Planning and Management**
Spring. 3 credits. Prerequisites: CEE 3610 or permission of instructor. H. O. Gao.
For description, see CEE 6650.

**[CEE 4710 Fundamentals of Structural Mechanics**
Fall. 3 credits. Prerequisites: ENGRD 2020, MATH 2940. Next offered 2009–2010. Staff.
Topics include beam bending; beams on elastic foundations; stability analysis for columns and beam-columns; linear elasticity; numerical solutions for linear elasticity problems; and applications including stress concentration, torsion, and plates.]

**CEE 4720 Introduction to the Finite Element Method**
Fall. 3 credits. Prerequisites: CEE 3710, 3720, and 4710. P. Koutsourelakis.
Covers the formulation of the finite element method in 2-D and 3-D continuum, basic 2-D and 3-D continuum isoparametric elements, modeling and programming aspects of the finite element method, and static and transient problems. A large part of the course is devoted to understanding element formulations, testing elements (patch test), and addressing problems such as shear and volumetric locking, among others. Emphasis is placed on understanding fundamental aspects of the method for making intelligent use of commercial software and obtaining a strong background for moving to further study and research.

**CEE 4730 Design of Concrete Structures**
Fall. 4 credits. K. C. Hover.
Centered on the design of a multi-story building that is initially planned with masonry bearing walls and precast-prestressed concrete floors. The masonry walls are then replaced with steel beams and columns. In the next phase the precast concrete is replaced with cast-in-place reinforced concrete. Finally, the structural steel elements will be replaced with a reinforced concrete framing system. The course explore gravity loads, wind loads, and earthquake loads, and the behavior of individual members and the structure as a whole.

**CEE 4740 Design of Steel Structures**
Spring. 4 credits. Prerequisite: ENGRD 2020 or permission of instructor. C. Earls.

An introductory course focused on the use of solid and structural mechanics to qualify elementary steel building and bridge behavior to enable design.

**CEE 4750 Concrete Materials and Construction**

Spring. 3 credits. K. C. Hover.

Covers the materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. Topics include cement chemistry and physics, mix design, admixtures, engineering properties, testing of fresh and hardened concrete, and the effects of construction techniques on material behavior.

**[CEE 4760 Evaluation and Failure of Structures**

Spring. 3 credits. Prerequisites: ENGRD 2020, 2610, and 2030; CEE 3710 and 4730. Staff.

This course teaches material and structural evaluation through the lens of failure. The course builds upon and integrates what students have learned in courses in physics, mechanics, dynamics, materials science, structural modeling/analysis, and design. In addition, the course teaches the physics of methods used for condition assessment of structures (e.g., stress wave propagation, electromagnetic wave propagation, heat flow), introduces students to structural damage and assessment of damage caused by earthquake/wind loads on structures, and introduces students to blast/impact loadings on structures and the concept of progressive collapse.]

**CEE 4770 Introduction to Composite Materials (also MAE/TAM 4550, MSE 5550)**

Fall. 3 credits. P. Petrina.

For description, see TAM 4550.

**CEE 4780 Structural Dynamics and Earthquake Engineering**

Spring. 3 credits. Enrollment limited to juniors and seniors. M. D. Grigoriu.

Covers modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

**CEE 4810 LRFD-Based Engineering of Wood Structures (also BEE 4791)**

Spring. 3 credits. Prerequisite: ENGRD 2020.

For description, see BEE 4810 under "College of Agriculture and Life Sciences."

**CEE 4920 Engineers for a Sustainable World: Engineering in International Development**

Fall. 3 credits. F. Vanek and P. Doing.

Engineering-based group service projects offer real-life engineering research and design experience, from problem formulation through implementation. They may be international or local, and may relate to any kind of engineering. Students work on interdisciplinary teams with a project supervisor and a partner community organization. Course readings and a writing assignment cover the relationship between engineering and international development, the philosophy and politics of technology, and ethics in engineering practice.

**CEE 5021–5022 Design Project**

Fall, spring. 3 credits each semester. Requirement for students in M.Eng. (civil and environmental) program. Staff.

CEE design projects present students with an exemplary design experience that reflects those carried out in the course of professional practice. Projects are typically performed by student design groups, and the topics reflect the diverse specialty areas of the civil and environmental engineering field as described below.

**CEE 5021–5022 Project in Environmental and Water Resources Systems**

**CEE 5031–5032 Project in Environmental Fluid Mechanics and Hydrology**

Staff.

**CEE 5041–5042 Project in Geotechnical Engineering**

F. H. Kulhawy.

Design of major geotechnical engineering project. Planning and preliminary design during fall semester; final design completed in January intersession.

**CEE 5051–5052 Agua Clara: Sustainable Water Supply Project**

M. Weber-Shirk.

For more information, see aguaclara.cee.cornell.edu.

**CEE 5061–5062 Project in Transportation Engineering**

Systems analysis of a substantial transportation service.

**CEE 5071–5072 Project in Structural Engineering**

C. Earls.

A project-centered course focusing on the design of a major engineering structure. Planning and a preliminary design are completed during the fall semester; the comprehensive final design is completed in the January intersession.

**CEE 5073–5074 Project in Civil Engineering Materials**

Staff.

**CEE 5081–5082 Project in Civil Infrastructure Systems**

Staff.

Analysis of a problem in civil infrastructure.

**CEE 5240 Applied Systems Engineering (also CS 5040, ECE/ORIE 5120, MAE 5910, SYSEN 5100)**

Fall. 3 credits. Prerequisite: senior or graduate standing in engineering field; concurrent or recent (past two years) enrollment in group-based project with strong system design component approved by course instructor. A. R. George and R. Roundy.

For description, see SYSEN 5100.

**CEE 5252 System Architecture, Behavior, and Optimization (also CS 5050, ECE 5130, ORIE 5142, MAE 5920, SYSEN 5200)**

Spring. 3 credits. Prerequisite: CEE 5240/CS 5040, ECE/ORIE 5120, MAE 5910, or SYSEN 5200). Staff.

For description, see SYSEN 5200.

**[CEE 5290 Heuristic Methods for Optimization (also CS/CIS 5720 ORIE 5330)**

Fall. 3 or 4 credits. Prerequisites: graduate standing or CS, ENGRD 2110 or 3510; ENGRD 3200 or permission of instructor. Next offered 2009–2010. C. A. Shoemaker.

Teaches heuristic search methods including simulated annealing, tabu search, genetic algorithms, derandomized evolution strategy, and random walk developed for optimization of combinatorial- and continuous-variable problems. Application project options include wireless networks, protein folding, job shop scheduling, partial differential equations, satisfiability, or independent projects. Statistical methods are presented for comparing algorithm results. Advantages and disadvantages of heuristic search methods for both serial and parallel computation are discussed in comparison with other optimization algorithms.]

**CEE 5900 Project Management**

Fall, spring. 4 credits. Prerequisite: permission of instructor. F. J. Wayno.

Core graduate course in project management for people who will manage technical or engineering projects. Focuses both on the "technical" tools of project management (e.g., methods for planning, scheduling, and control) and the "human" side (e.g., forming a project team, managing performance, resolving conflicts), with somewhat greater emphasis on the latter.

**CEE 5910 Engineering Management Project**

Fall. 3 credits. Prerequisite: permission of instructor. Staff.

Intensive evaluation of the management aspects of a major engineering project or system. Most students work on a large group project in the area of project management, but students may also work singly or in small groups on an engineering management topic of special interest to them.

**CEE 5920 Engineering Management Project**

Spring. 3 credits. Prerequisite: permission of instructor. Staff.

Continuation of CEE 5910.

**CEE 5930 Engineering Management Methods**

Spring. 3 credits. Prerequisites: CEE 3230 and 3040 or equivalent. M. A. Turnquist.

Methods for managing data and transforming data into information. Modeling as a means to synthesize information into knowledge that can form the basis for decisions and actions. Application of statistical methods and optimization to managerial problems in operations, forecasting, and resource allocation.

**[CEE 5940 Economic Methods for Engineering and Management (also ECON 4940)]**

**CEE 5950 Construction Planning and Operations**

Fall. 3 credits. P. G. Carr.

The course prepares students for responsibilities in overseeing the engineering and management of construction; on time—on budget. Emphasis is placed on the management processes for organizing, planning, and controlling the activities of complex development and construction programs. Students study the contracts for engineering, architecture, and construction; focusing on cost estimation and schedule control, responsibilities and risks, and the relationships among owners, designers, contractors, and suppliers. The potential for project disruption is discussed with special emphasis on dispute resolution methods.

**[CEE 5960 Management Issues in Forensic Engineering**

Fall. 3 credits. Next offered 2009–2010. P. G. Carr.

Introduction to Management issues in Forensic Engineering, Contract Administration and

Dispute Resolution, with particular emphasis on contract formation, performance, breach, and remedies. Through case studies in forensics, the engineer's standard of care and design obligations are explored. The engineer's technical and ethical duties to the client, the contractors, and the public are examined.]

**CEE 5970 Risk Analysis and Management (also TOX 5970)**
Spring. 3 credits. Prerequisite: introduction to probability and statistics (e.g., CEE 3040, ENGRD 2700, ILRST 2100, BTRY 3010, or AEM 2100); two semesters of calculus; senior or graduate standing or permission of instructor. J. R. Stedinger.
Develops a working knowledge of risk terminology and reliability engineering, analytic tools and models used to analyze safety, environmental and technological risks, and social and psychological risk issues. Discussions address life risks in the United States historical accidents, natural hazards, threat assessment, transportation risks, industrial accidents, waste incineration, air pollution modeling, public health, regulatory policy, risk communication, and risk management.

**CEE 5980 Intro to Decision Analysis**
Fall. 3 credits. Prerequisite: introduction to probability and statistics course such as CEE 3040, ENGRD 2700, ILRST 2100, BTRY 3010, or AEM 2100. For seniors and graduate students or by permission of instructor. L. K. Nozick.
Framework to structure the way we think about decision situations that are complicated by uncertainty, complexity, and competing objectives. Specific decision-analysis concepts and tools, such as decision trees, sensitivity analysis, value of information, and utility theory. Applications to all areas of engineering and life. Includes a group project to analyze a real-world decision.

**CEE 6015 Special Topics—Remote Sensing**
On demand. 1–6 credits. W. D. Philpot.
Students may elect to undertake a project in remote sensing. The work is supervised by a professor in this subject area.

**CEE 6020 Environmental Seminar**
Fall. 1 credit. Staff.
Presents topics of current interest.

**CEE 6021 Seminar—Environmental and Water Resources Systems Analysis**
Spring. 1 credit. Prerequisite: permission of instructor. C. A. Shoemaker.
Graduate students and faculty members give informal lectures on various topics related to ongoing research in environmental or water resources systems planning and analysis.

**CEE 6025 Special Topics in Environmental and Water Resources Systems Analysis**
Offered on demand. 1–6 credits. D. P. Loucks.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

**CEE 6030 Seminar—Hydraulics**
Spring. 1 credit. Requirement for graduate students majoring in hydraulics or hydraulic engineering. Open to undergraduates and graduates. Staff.
Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

**CEE 6035 Special Topics in Hydraulics**
On demand. 1–6 credits. Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

**CEE 6045 Special Topics in Geotechnical Engineering**
On demand. 1–6 credits. Staff.
Supervised study of special topics not covered in the formal courses.

**CEE 6051 Seminar—Environmental Quality Engineering**
Spring. 1 credit. Prerequisite: graduate students in environmental engineering. R. E. Richardson.
Presentation and discussion of current research in environmental engineering.

**CEE 6055 Special Topics in Environmental Engineering**
On demand. 1–6 credits. Staff.
Supervised study in special topics not covered in formal courses.

**CEE 6060 Seminar—Transportation System Engineering**
Fall, spring. 1 credit. Staff.
Presents topics of current interest.

**CEE 6065 Special Topics in Transportation**
On demand. 1–6 credits. Staff.
Advanced subject matter not covered in depth in other regular courses.

**CEE 6070 Seminar—Civil Infrastructure**
Fall, spring. 1 credit. Requirement for first-year graduate students. Staff.
Presents topics of current interest.

**CEE 6075 Special Topics in Structural Engineering**
On demand. 1–6 credits. Staff.
Individually supervised study or independent design or research in specialized topics not covered in regular courses. Occasional offering of such special courses as Shell Theory and Design, and Advanced Topics in Finite Element Analysis.

**CEE 6080 Seminar—Engineering Systems and Management**
Fall, spring. 1 credit. Staff.
Presents topics of current interest.

**CEE 6095 Special Topics in Engineering Management**
On demand. 1–6 credits. Staff.
Individually supervised study of one or more specialized topics not covered in regular courses.

**CEE 6100 Remote Sensing Fundamentals (also CSS 6100)**
Fall. 3 credits. W. D. Philpot.
Introduction to the principles, equipment, and methods used in obtaining information about earth resources and the environment from aircraft or satellite sensors. Topics include basic interactions of electromagnetic radiation with the earth, sensors, sensor and ground-data acquisition, data analysis and interpretation, and project design in the form of a proposal to use remote sensing for a specific application.

**CEE 6150 Digital Image Processing**
Spring. 3 credits. W. D. Philpot.
An introduction to digital image-processing concepts and techniques, with emphasis on remote-sensing applications. Topics include image acquisition, enhancement procedures, spatial and spectral feature extraction, and classification, with an introduction to hyperspectral data analysis. Assignments require the use of image-processing software and graphics.

**CEE 6200 Water-Resources Systems Engineering**
Spring. 3 credits. Prerequisites: CEE 3230 and 5930 or BEE 4750. D. P. Loucks.
Development and application of deterministic and stochastic optimization and simulation models for aiding in water-resources planning and management. Covers river-basin modeling, including water allocation to multiple purposes, reservoir design and operation, irrigation planning and operation, hydropower-capacity development, flow augmentation, flood control and protection, ecological habitat restoration, and water-quality prediction and control.

**[CEE 6210 Stochastic Hydrology**
Spring. 3 credits. Prerequisites: CEE 3040 or permission of instructor. Offered on demand. J. R. Stedinger.
Course examines statistical, time series, and stochastic optimization methods used to address water resources planning and management problems involving uncertainty objectives and hydrologic inputs. Statistical issues include: maximum likelihood and moments estimators; censored data sets and historical information; probability plotting; Bayesian inference; regionalization methods; ARMA models; multivariate stochastic streamflow models; stochastic simulation; and stochastic reservoir-operation optimization models.]

**[CEE 6230 Environmental Quality Systems Engineering**
Fall. 3 credits. Prerequisites: MATH 2940, optimization, and graduate standing or permission of instructor. C. A. Shoemaker.
Applications of optimization, simulation methods, and uncertainty analysis to the prevention and remediation of pollution. Case studies include: regional waste and wastewater treatment, restoration of dissolved oxygen levels in rivers, and reclamation of contaminated groundwater. Applications use linear programming, integer, dynamic, nonlinear programming, and sensitivity analysis.]

**CEE 6290 Numerical Methods for Engineers**
Fall. 3 credits. P. J. Diamessis.
The primary focus is algorithm implementation within the context of engineering applications (spanning fluid and solid/fracture mechanics and beyond). Student projects will include parallel implementation using resources at the Theory Center. Course topics will include: Sources of error and error propagation, eigenvalue/eigenvector computation, solution of linear systems via direct or iterative methods and issues of parallel implementation, least squares approximation of lab/simulation data, solution of non-linear equations, interpolation in one and two dimensions, fast Fourier transforms (serial vs. parallel) and wavelets.

**CEE 6300 Computational Fluid Dynamics for Environmental Flows**
Spring. 3 credits. Course offered on demand. Please contact professor if interested in this course. P. J. Diamessis.
Higher-order spatial discretization schemes (spectral and compact-finite difference). One-dimensional nonlinear partial differential equations (Burgers eqn., Korteweg-DeVries eqn. and Shallow Water eqns.) and

implications for environmental fluid flow simulations. Two-dimensional problems and fast iterative solvers. Numerical solution of the incompressible Navier-Stokes equations in an environmental/geophysical context. Advanced topics may include: Introduction to turbulence subgrid scale modeling in stratified/rotating flow, free surface flow modeling and representation of complex topography.

**CEE 6310 Computational Simulation of Flow and Transport in the Environment**

Spring. 3 credits. Prerequisites: MATH 2940 or equivalent, ENGRD 3200 or experience in numerical methods and programming, and elementary fluid mechanics. Staff.

Covers fundamental equations of saturated and unsaturated flow in porous media; flow in fractured media; numerical modeling of transport in porous media; diffusion and advective diffusion in one, two, and three dimensions; anisotropy; and additional terms for reactive substances. Teaches various numerical methods including finite difference, finite elements, and boundary elements.

**CEE 6320 Hydrology**

Spring. 3 credits. Prerequisite: CEE 3310. W. H. Brutsaert.

Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers and scientists. Covers: physical and statistical prediction methods for design related to hydrologic processes; hydrometeorology and evaporation; infiltration and base flow; surface runoff and channel routing; linear and nonlinear hydrologic systems; and storage routing and unit hydrograph methods.

**[CEE 6330 Flow in Porous Media and Groundwater**

Fall. 3 credits. Prerequisite: CEE 3310. Next offered 2008–2009. Please contact professor if interested in this course. W. H. Brutsaert.

Fluid mechanics and equations of single-phase and multiphase flow; methods of solution. Applications involve aquifer hydraulics, pumping wells; drought flows; infiltration, groundwater recharge; land subsidence; seawater intrusion, miscible displacement; and transient seepage in unsaturated materials.]

**[CEE 6340 Boundary Layer Meteorology**

Fall. 3 credits. Prerequisite: CEE 3310 or permission of instructor. Next offered 2008–2009. Please contact professor if interested in this course. W. H. Brutsaert.

Physical processes in the lower atmospheric environment: turbulent transport in the atmospheric boundary layer, surface-air interaction, disturbed boundary layers, radiation. Applications include sensible and latent heat transfer from lakes, plant canopy flow and evapotranspiration, turbulent diffusion from chimneys and cooling towers, and related design issues.]

**[CEE 6350 Small and Finite Amplitude Water Waves**

Spring. 3 credits. Taught based on demand; please contact professor if interested in this course. P. L.-F. Liu.

Reviews linear and nonlinear theories of ocean waves. Discusses the applicability of different wave theories to engineering problems.]

**CEE 6360 Environmental Fluid Mechanics**

Spring. 3 credits. Taught based on demand; please contact professor if interested in this course. E. A. Cowen.

Covers analytic and modeling perspectives of environmental flows; mechanics of layered and continuously stratified fluids: internal waves, density currents, baroclinic motions, and turbulence; jets and plumes and their behavior in the environment; turbulent diffusion, shear flow dispersion, and wave-induced mixing processes; and applications to mixing processes in rivers, lakes, estuaries, and the coastal ocean.

**CEE 6370 Experimental Methods in Fluid Dynamics (also MAE 6272)**

Spring. 4 credits. Pre- or corequisites: CEE 3310 or equivalent and CEE 3040 or equivalent. E. A. Cowen.

Introduction to experimental data collection and analysis, in particular as they pertain to fluid flows. Covers computer-based experimental control, analog and digital data acquisition, discrete sampling theory, digital signal processing, uncertainty analysis. Also covers analog transducers, acoustic and laser Doppler velocimetry, full-field (2-D) quantitative imaging techniques. Includes laboratory experiments and a project.

**CEE 6400 Foundation Engineering**

Fall. 3 credits. Prerequisite: CEE 3410. F. H. Kulhawy.

Covers soil exploration, sampling, and in-situ testing techniques; bearing capacity, stress distribution, and settlement; design of shallow and deep foundations; compaction and site preparation; and seepage and dewatering of foundation excavations.

**CEE 6410 Retaining Structures and Slopes**

Spring. 3 credits. Prerequisite: CEE 3410. T. D. O'Rourke.

Covers Earth pressure theories; design of rigid, flexible, braced, tied-back, slurry wall, soil nailing, and reinforced soil structures; stability of excavation, cut, and natural slopes; and design problems stressing application of course material under field conditions of engineering practice.

**[CEE 6440 Environmental Site and Remediation Engineering**

Spring. 3 credits. Prerequisite: CEE 3410 or equivalent or permission of instructor. Next offered 2009–2010. T. D. O'Rourke.

Covers principles of hydrogeology, contaminant migration, and remediation technologies related to geotechnical and environmental engineering. Emphasizes environmental site assessment, site feasibility studies, selection of remediation procedures, and engineered landfills. Design problems are based on real projects and involve visits from practicing engineers.]

**CEE 6530 Water Chemistry for Environmental Engineering**

Fall. 3 credits. Prerequisite: one semester of college chemistry or permission of instructor. J. J. Bisogni.

Covers principles of chemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters. Topics include chemical thermodynamics, reaction kinetics, acid-base equilibria, mineral precipitation/dissolution, and electrochemistry. Focuses on the mathematical description of chemical reactions relevant to engineered processes and natural systems, and the numerical or graphical solution of these problems.

**[CEE 6540 Aquatic Chemistry**

Spring. 3 credits. Prerequisite: CEE 6530 or CHEM 2870–2880. J. J. Bisogni.

Applies concepts of chemical equilibria to natural aquatic systems. Topics include acid-base reactions, buffer systems, mineral precipitation, coordination and redox reactions, Eh-pH diagrams adsorption phenomena, humic acid chemistry, and chemical-equilibria computational techniques. In-depth coverage of topics covered in CEE 6530.]

**CEE 6550 Transport, Mixing, and Transformation in the Environment**

Fall. 3 credits. Prerequisite: CEE 3310. Staff.

Application of fluid mechanics to problems of transport, mixing, and transformation in the water environment. Introduction to advective, diffuse, and dispersive processes in the environment. Boundary interactions: air-water and sediment-water processes. Introduction to chemical and biochemical transformation processes. Applications to transport, mixing, and transformation in rivers, lakes, and coastal waters.

**CEE 6560 Physical/Chemical Process**

Fall. 3 credits. Pre- or corequisite: CEE 6530 or permission of instructor. J. M. Gossett.

Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in the environment. Analysis and design of treatment processes and systems.

**CEE 6570 Biological Processes**

Spring. 3 credits. Prerequisites: introductory microbiology and CEE 6560, or permission of instructor. J. M. Gossett.

Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in the environment. Bioenergetics analysis, stoichiometry, biokinetic, and design of biological treatment process.

**CEE 6580 Biodegradation and Biocatalysis**

Spring. 3 credits. Prerequisites: CEE 4510 or BIOMI 2900 or equivalent; CEE 3510 or CHEME 3900 or permission of instructor. R. E. Richardson.

Students explore the use of microbes in biodegradation and biocatalysis as well as the molecular techniques (i.e., analysis of DNA, RNA, and proteins) commonly used in these applications. Lectures cover enzyme classes and kinetics, selective isolation of organisms with desired bioconversion capabilities, effects of environmental parameters and cell-to-cell communication on gene expression, methods in microbial molecular biology, and contemporary case studies in biodegradation and biocatalysis. Laboratory sessions give students hands-on experience in molecular and analytical methods. Student teams design and then construct a bioreactor employing their own environmental isolates that degrade a selected contaminant or produce a desired compound.

**[CEE 6610 Urban Transportation Planning and Modeling]**

**[CEE 6620 Urban Transportation Network Design and Analysis**

Fall. 3 credits. Prerequisite: CEE 3610 or permission of instructor. Next offered 2009–2010. M. A. Turnquist.

Covers the development and use of mathematical models for the design and analysis of urban transportation networks, including formulations and solution procedures for deterministic user equilibrium and stochastic user equilibrium. Students apply these tools to a substantive real-world case study and estimation of origin–destination tables.]

**[CEE 6630 Network Flows and Algorithms**

Spring. 3 credits. Prerequisite: CEE 6620 or permission of instructor. Offered alternate years; next offered 2009–2010. M. A. Turnquist.

Algorithms for network flow problems encountered in transportation systems modeling, including shortest path, multi-objective shortest path, minimum cost flows, multi-commodity flows, and generalized flows. Applications to vehicle routing, dynamic vehicle allocation, and network design.]

**CEE 6650 Environment/Energy and Transportation Planning and Management**

Spring. 3 credits. Prerequisites: CEE 3610 or permission of instructor. H. O. Gao.

The course focuses on the nexus of transportation and environment, energy, and climate-change concerns. It is interdisciplinary: drawing upon transportation, environment, urban planning, statistics, economics, and policy. The course covers both the theoretical and practical aspects of relevant topics including mobile emissions inventory estimation, renewable fuels, air quality impact and life cycle benefit assessment of alternative fuels/vehicles, Intelligent Transportation Systems (ITS) and urban sprawl, and congestion mitigation and air quality (CMAQ). Students will apply course materials to real-world cases and projects.

**[CEE 6710 Fundamentals of Structural Mechanics]**

**CEE 6720 Introduction to the Finite Element Method**

Fall. 3 credits. Prerequisites: CEE 3710, 3720, and 4710. P. Koutsourelakis.

Covers the formulation of the finite element method in 2-D and 3-D continuum, basic 2-D and 3-D continuum isoparametric elements, modeling and programming aspects of the finite element method, and static and transient problems. A large part of the course is devoted to understanding element formulations, testing elements (patch test), and addressing problems such as shear and volumetric locking, among others. Emphasis is placed on understanding fundamental aspects of the method for making intelligent use of commercial software and obtaining a strong background for moving to further study and research.

**CEE 6730 Design of Concrete Structures**

Fall. 4 credits. Prerequisite: CEE 3710 or permission of instructor. K. C. Hover.

Centered on the design of a multi-story building that is initially planned with masonry bearing walls and precast-prestressed concrete floors. The masonry walls are then replaced with cast-in-place reinforced concrete. Finally, the structural steel elements are replaced with a reinforced concrete framing system. The course explores gravity loads, wind loads, and earthquake loads, and the behavior of individual members and the structure as a whole.

**CEE 6750 Concrete Materials and Construction**

Spring. 3 credits. K. C. Hover.

Covers the materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. Topics include cement chemistry and physics, mix design, admixtures, engineering properties, testing of fresh and hardened concrete, and the effects of construction techniques on material behavior.

**CEE 6760 Advanced Composite Materials (also TAM 6550, MAE/MSE 6550)**

Spring. 4 credits. CEE 4770/MAE 4550/MSE 5550/TAM 4550 not a prerequisite but excellent background.

For description, see TAM 6550.

**[CEE 6770 Engineering Analysis**

Fall. 3 credits. Prerequisite: permission of instructor. Next offered 2009–2010. M. D. Grigoriu.

Vector spaces, linear transformations, and eigenvalue problems with applications to matrix structural analysis, linear dynamics, stability, and principal stresses, strains, and moments of inertia. Fourier analysis for periodic and non-periodic functions, with applications to the solution of ordinary differential equations, beams, plates, and other structural mechanics problems. Partial differential equations with applications to the analysis of static and dynamic response of continuous systems and transport problems.]

**CEE 6780 Structural Dynamics and Earthquake Engineering**

Spring. 3 credits. M. D. Grigoriu.

Covers modal analysis, numerical methods, and frequency-domain analysis. Introduces earthquake-resistant design.

**[CEE 6790 Evaluation and Failure of Structures]**

**CEE 6860 Civil Infrastructure Systems**

Fall. 3 credits. Prerequisites: probability and statistics course (CEE 3040 or equivalent), or permission of instructor. Recommended: engineering economics course (CEE 3230 or equivalent). S–U or letter grades. F. Vanek.

Introduction to the framing and solution of civil infrastructure problems using a systems engineering approach. Systems tools, such as optimization, life-cycle cost analysis, decision analysis, simulation, Markov modeling, and risk analysis, are examined through case studies related to civil infrastructure.

**CEE 6900 Creativity, Innovation, and Leadership**

Spring. 3 credits. Pre- or corequisite: CEE 5800 or permission of instructor. F. J. Wayno.

Graduate course designed to help aspiring engineering managers to better understand individual creativity and organizational innovation and to develop the required skills to play a productive role in fostering both. Not incidentally, the course will also help students who take it to become more creative themselves. The course is highly participative and has a flow that moves from the individual-—to the group-—to the organization, with theory, research results, and practical skills-development woven seamlessly together.

**CEE 6910 Principles of Project Leadership (also SYSEN 6910)**

Spring. 3 credits. Prerequisite: permission of instructor. F. J. Wayno.

Core graduate course in project management for people who will manage technical or engineering projects. Focuses both on the "technical" tools of project management (e.g., methods for planning, scheduling, and control) and the "human" side (e.g., forming a project team, managing performance, resolving conflicts), with somewhat greater emphasis on the latter. Offered as a distance learning course only.

**CEE 6930 Public Systems Modeling**

Fall. 4 credits. D. P. Loucks.

An introduction to the art of model building and use, especially related to public sector planning and management issues. The course will focus on the quantitative systems approach for identifying and evaluating alternative possible decisions and their physical, economic, environmental, and social impacts. Modeling methods include various deterministic and probabilistic optimization and simulation models, decision analysis, evolutionary search algorithms, and statistical models applied to a variety of public sector issues. The aim of all of this "modeling technology" is to help us generate and communicate information that can assist and better inform public decision making.

**CEE 6940 Research in Engineering Management**

On demand. 1–6 credits. Staff.

The student may select an area of investigation in engineering management. Results should be submitted to the instructor in charge in the form of a research report.

**CEE 7010 Research—Remote Sensing**

On demand. 1–6 credits. W. D. Philpot.

For students who want to study one particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design procedures.

**CEE 7020 Environmental and Water Resources Systems Analysis Research**

On demand. 1–6 credits. Prerequisite: permission of instructor. Preparation must be suitable to investigation to be undertaken. Staff.

Investigations of particular environmental or water resources systems problems.

**CEE 7030 Research in Environmental Fluid Mechanics and Hydrology**

On demand. 1–6 credits. Staff.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either experimental or theoretical in nature. Results should be submitted to the instructor in charge in the form of a research report.

**CEE 7040 Research in Geotechnical Engineering**

On demand. 1–6 credits. Staff.

For students who want to pursue a particular geotechnical topic in considerable depth.

**CEE 7050 Research in Environmental Engineering**

On demand. 1–6 credits. Staff.

For students who want to study a particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design and analysis procedures.

**CEE 7070 Research in Structural Engineering**

On demand. 1–6 credits. Staff.

Pursues a branch of structural engineering beyond what is covered in regular courses. Theoretical or experimental investigation of suitable problems.

**CEE 7073 Civil and Environmental Engineering Materials Project**

On demand. 1–3 credits. Staff.

Individual projects or reading and study assignments involving engineering materials.

**CEE 7360 Turbulence and Turbulent Mixing in Environmental Stratified Flows**

Spring. 3 credits. Prerequisite: CEE 6550 or a second course in fluid mechanics or with instructor's permission. Course offered on demand. Please contact professor if interested in this course. P. J. Diamessis.

Fundamentals of stably stratified flows, stratified homogeneous turbulence (spectra, lengthscales, and timescales), kinematics of diapycnal mixing, basic turbulent flow processes in homogeneous and stratified fluids (shear layers, wakes, boundary layers, etc.), energy budget analysis, and parameterizations of geophysical turbulence. Additional topics may include: fossil turbulence theory and vortex-internal wave decomposition in strongly stratified turbulence.

**CEE 7400 Engineering Behavior of Soils**

Fall. 3 credits. Prerequisite: CEE 3410. H. E. Stewart.

Detailed study of the physiochemical nature of soil. Stress states due to geostatic loading and stress-history effects. In-depth evaluation of stress-strain-strength, compressibility, and hydraulic conductivity of natural soils.

**CEE 7410 Rock Engineering**

Fall. 3 credits. Prerequisite: CEE 3410 or permission of instructor. Recommended: introductory geology. T. D. O'Rourke.

Geological and engineering classifications of intact rock, discontinuities, and rock masses. Includes laboratory and field evaluation of properties. Covers: stress states and stress analysis; design of foundations on, and openings in, rock masses; analysis of the stability of rock slopes; and rock blasting.

**[CEE 7440 Advanced Foundation Engineering**

Spring. 2 credits. Prerequisite: CEE 6400. Next offered 2008–2009. F. H. Kulhawy.

Continuation of CEE 6400, with detailed emphasis on special topics in soil-structure interaction. Typical topics include lateral and pullout loading of deep foundations, pile group behavior, foundations for offshore structures, foundations for special structures.]

**CEE 7450 Soil Dynamics**

Spring. 3 credits. Prerequisite: permission of instructor. H. E. Stewart.

Study of soil behavior under dynamic loading conditions. Foundation design for vibratory loadings. Introductory earthquake engineering including field and laboratory techniques for determining dynamic soil properties and liquefaction potential. Covers design of embankments and retaining structures under dynamic loading conditions.

**[CEE 7460 Embankment Dam Engineering**

Spring. 2 credits. Prerequisites: CEE 6410 and 7410, or permission of instructor. Next offered 2009–2010. F. H. Kulhawy.

Principles of analysis and design for earth and rockfill dams. Materials, construction methods, internal and external stability, seepage and drainage, performance monitoring, abutment and foundation evaluation. Introduction to tailings dams.]

**CEE 7620 Practicum in Modeling Transportation Systems**

Fall. 3 credits. Prerequisites: CEE 6610, 6620, and 6630. L. K. Nozick.

**CEE 7700 Engineering Fracture Mechanics**

Fall. 3 credits. Prerequisite: CEE 6720 or equivalent and TAM 7530, or permission of instructor. A. Ingraffea.

Computational and physical modeling of crack growth processes. Finite and boundary element-based simulation of brittle fracture initiation and propagation, fatigue crack growth, and elasto-plastic and cohesive approaches to inelastic crack growth. Element formulation, meshing and remeshing, interactive steering. Case studies across scales from geomechanics to micromechanics, and including metals, ceramics, and polymers. Laboratory techniques for fracture toughness, crack growth rate, and trajectory testing.

**[CEE 7710 Stochastic Mechanics in Science and Engineering**

Fall. 3 credits. Prerequisite: permission of instructor. Next offered 2009–2010. M. D. Grigoriu.

Review of probability theory, stochastic processes, and Ito formula with illustrations by Monte Carlo Simulation. Analytical and numerical methods for solving stochastic problems defined by algebraic, differential, and integral equations with random/deterministic coefficients and random/deterministic input. Applications include: solution of Laplace, transport, Schrodinger, and other deterministic partial differential equations; dynamic systems subjected to Gaussian and non-Gaussian noise; random eigenvalue problems; and homogenization, structure evolution, and pattern formation for random heterogeneous materials.]

**[CEE 7720 Random Vibration**

Fall. 3 credits. Prerequisites: MAE 3260 and ENGRD 2700, or equivalent, and permission of instructor. Next offered 2008–2009. M. D. Grigoriu.

Reviews random-process theory, simulation, and first-passage time. Linear random vibration: second-moment response descriptors and applications from fatigue; seismic analysis; and response to wind, wave, and other non-Gaussian load processes. Nonlinear random vibration: equivalent linearization, perturbation techniques, Fokker-Planck and Kolomogorov equations, Itô calculus, and applications from chaotic vibration, fatigue, seismic analysis, and parametrically excited systems.]

**[CEE 7730 Structural Reliability**

Fall. 3 credits. Prerequisite: permission of instructor. Next offered 2009–2010. M. D. Grigoriu.

Review of probability theory, practical measures for structural reliability, second-moment reliability indices, probability models for strength and loads, probability-based design codes, reliability of structural systems, imperfection-sensitive structures, fatigue, stochastic finite-element techniques, and elementary concepts of probabilistic fracture mechanics.]

**[CEE 7740 Advanced Structural Concrete**

Fall. 3 credits. Next offered 2009–2010. Staff.

Covers the fundamental aspects of the mechanical behavior of concrete subjected to axial and multiaxial states of stress, rate effects, time-dependent deformations, and multiscale modeling. Includes the behavior of reinforced concrete membrane elements subjected to plane states of stress, torsion, limit analysis, and gives an introduction to finite element modeling of reinforced concrete structures.]

**CEE 7750 Nonlinear Finite Element Analysis**

Spring. 3 credits. W. Aquino.

Covers fundamental aspects of nonlinear finite element analysis including geometric and material nonlinearity. Also covers total and updated lagrangian formulations, implementation of constitutive models, numerical solutions of global nonlinear systems of equations, and regularization techniques for softening materials.

**[CEE 7760 Advanced Topics in Stability**

Spring. 3 credits. Prerequisite: CEE 3740 or equivalent. Next offered 2009–2010. C. Earls.]

**CEE 7770 Computational Solid and Structural Mechanics**

Spring. 3 credits. Staff.

This course covers the formulation and numerical solution of problems of solids and structures using the finite element method. Topics include a review of solid mechanics: nonlinear kinematics, invariance, first and second law of thermodynamics, and constitutive equations with internal variables; strong forms and weak forms; implicit and explicit algorithms; variants of Newton's method; and Lagrangian and Eulerian formulations. Application topics are chosen from the following areas: 3D finite elasticity, fully nonlinear beams and shells, distributed and discrete damage, contact-impact, and plasticity.

**CEE 7790 Advanced Behavior of Metal Structures**

Fall. 4 credits. Prerequisite: CEE 3410 or permission of instructor. C. Earls.

An advanced course focused on the use of solid and structural mechanics to quantify more complex aspects of metal structure behavior so as to enable more sophisticated approach to design.

**CEE 8100 Thesis—Remote Sensing**

Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. W. D. Philpot.

The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8200 Thesis—Environmental and Water Resource Systems**

Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.

The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8300 Thesis—Environmental Fluid Mechanics and Hydrology**
Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.
The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8400 Thesis—Geotechnical Engineering**
Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.
The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8500 Thesis—Environmental Engineering**
Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.
The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8600 Thesis—Transportation Systems Engineering**
Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.
The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8700 Thesis—Structural Engineering**
Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.
The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

**CEE 8800 Thesis—Civil Infrastructure Systems**
Fall, spring. 1–12 credits. Students must register for credit with professor at start of each semester. Staff.
The student selects a thesis research topic with the advice of the faculty member in charge and pursues it either independently or in conjunction with others working on the same topic.

## COMPUTER SCIENCE

E. Tardos, chair; W. Arms, G. Bailey, K. Bala, K. Birman, C. Cardie, R. L. Constable, D. Fan, P. Francis, J. Gehrke, D. Greenberg, D. Gries, J. Halpern, J. E. Hopcroft, D. Huttenlocher, . James, T. Joachims, U. Keich, J. Kleinberg, R. Kleinberg, C. Koch, D. Kozen, L. Lee, S. Marschner, A. Myers, R. Pass, F. B. Schneider, B. Selman, D. Shmoys, E. G. Sirer, R. Teitelbaum, C. Van Loan, R. Zabih

The Department of Computer Science is part of the College of Arts and Sciences, Computing and Information Science (CIS), and the College of Engineering. For complete course descriptions, see the Computer Science listing in the CIS section.

**CS 1109 Fundamental Programming Concepts**
Summer. 2 credits. Prerequisite: pre-freshman standing or permission of instructor. Credit may not be applied toward engineering degree. S–U grades only.

**CS 1110 Introduction to Computing Using Java**
Fall, spring, summer. 4 credits. Assumes basic high school mathematics (no calculus), but no programming experience.

**CS 1112 Introduction to Computing Using MATLAB**
Fall, spring. 4 credits. Corequisite: MATH 1110, 1910, or equivalent. Assumes student is comfortable with mathematics (at the level of one semester of calculus) but has no prior programming experience.

**[CS 1113 Computing Using Java—Honors**
Fall or spring. 4. credits.]

**[CS 1114 Introduction to Computing Using MATLAB and Robotics**
Spring. 4 credits. Prerequisite: some programming experience. Next offered 2009–2010.]

**CS 1130 Transition to Object-Oriented Programming**
Fall, spring. 1 credit. Prerequisite: one course in programming. S–U grades only.

**CS 1132 Transition to MATLAB**
Fall, spring, summer. 1 credit. Prerequisite: one course in programming. S–U grades only.

**CS 1301 Introduction to Programming Web Applications**
Fall, weeks 1–7. 2 credits. Students must enroll in both CS 1301 and 1302.
For description, see INFO 1301 in CIS section.

**CS 1302 Introduction to Designing Web Applications**
Fall, weeks 8–14. 2 credits. Students must enroll in both CS 1301 and 1302. Prerequisite: CS 1301 or equivalent knowledge.
For description, see INFO 1302 in CIS section.

**CS 1610 Computing in the Arts (also CIS/ENGRI 1610, DANCE 1540, FILM 1750, MUSIC 1465, PSYCH 1650)**
Fall. 3 credits. Recommended: good comfort level with computers and some of the arts.

**CS 1620 Visual Imaging in the Electronic Age (also ARCH 4509, ART 1700, CIS 1620, ENGRI 1620)**
Fall. 3 credits.
For description, see ART 1700.

**CS 1710 Introduction to Cognitive Science (also COGST 1010, LING 1700, PHIL 1910, PSYCH 1020)**
Fall, summer. 3 credits.
For description, see COGST 1101.

**CS 2022 Introduction to C**
Fall, spring, usually weeks 1–4. 1 credit. Prerequisite: one programming course or equivalent programming experience. Credit granted for both CS 2022 and 2024 only if 2022 is taken first. S–U grades only.

**CS 2024 C++ Programming**
Fall. 2 credits. Prerequisite: one programming course or equivalent programming experience. Students who plan to take CS 2022 and 2024 must take 2022 first. S–U grades only.

**CS 2026 Introduction to C#**
Spring, usually weeks 5–8. 1 credit. Prerequisite: CS/ENGRD 2110 or equivalent experience. S–U grades only.

**CS 2042 Unix Tools**
Fall, usually weeks 5–8. 1 credit. Prerequisite: one programming course or equivalent programming experience. S–U grades only.

**CS 2044 Advanced UNIX Programming and Tools**
Spring, usually weeks 5–8. 1 credit. Prerequisite: CS 2042 or equivalent. S–U grades only.

**CS 2110 Object-Oriented Programming and Data Structures (also ENGRD 2110)**
Fall, spring, summer. 3 credits. Prerequisite: CS 1110, CS 1130, or CS 1113 or CS 1112 if completed before fall 2007 or equivalent course in Java or C++.

**CS 2111 Programming Practicum**
Fall, spring. 1 credit. Pre- or corequisite: CS/ENGRD 2110. Letter grades only.

**CS 2300 Intermediate Design and Programming for the Web (also INFO 2300)**
Spring. 3 credits. Prerequisite: CS 1301 and 1302 strongly recommended.
For description, see INFO 2300 in CIS section.

**CS 2800 Discrete Structures**
Fall, spring. 3 credits. Pre- or corequisite: one course in programming or permission of instructor.

**CS 2850 Networks (also ECON/INFO 2040, SOC 2090)**
Spring. 4 credits. Prerequisite: none.
For description, see ECON 2040.

**CS 3110 Data Structures and Functional Programming**
Fall, spring. 4 credits. Prerequisite: CS 2110 and 2111 or equivalent programming experience. Pre- or corequisite: CS 2800. Should not be taken concurrently with CS 3410 or 3420.

**CS 3220 Introduction to Scientific Computation (also ENGRD 3220)**
Spring, summer. 3 credits. Prerequisites: one programming course and MATH 2210 or 2940; knowledge of discrete probability and random variables at level of CS 2800.

**CS 3300 Data-Driven Web Applications (also INFO 3300)**
Spring. 3 credits. Prerequisite: CS/ENGRD 2110. CS majors may use only one of the following toward their degree: CS/INFO 3300 or CS 4321.
For description, see INFO 3300 in CIS section.

**CS 3410 Systems Programming**
Fall. 4 credits. Prerequisites: CS 2110 or equivalent programming experience. Should not be taken concurrently with CS 3110.

**CS 3420 Computer Organization (also ECE 3140)**
Spring. 4 credits. Prerequisite: CS 2110 or ENGRD 2300. Should not be taken concurrently with CS 3110.
For description, see ECE 3140.

**[CS 3700 Explorations in Artificial Intelligence (also INFO 3720)**
Spring. 3 credits. Prerequisites: MATH 1110 or equivalent, a statistics course, and CS/ ENGRD 2110 or permission of instructor. Next offered 2009–2010.
For description, see INFO 3720 in CIS section.]

**CS 3740 Computational Linguistics (also COGST 4240, LING 4424)**
Fall. 4 credits. Recommended: CS 2006.
For description, see LING 4424.

**CS 3810 Introduction to Theory of Computing**
Fall, summer. 3 credits. Prerequisite: CS 2800 or permission of instructor.

**[CS 4110 Programming Languages and Logics**
Fall or spring. 4 credits. Prerequisite: CS 3110 or permission of instructor. Next offered 2009–2010.]

**[CS 4120 Introduction to Compilers**
Spring. 3 credits. Prerequisites: CS 3110 or permission of instructor and CS 3420 or 3410. Corequisite: CS 4121.]

**[CS 4121 Practicum in Compilers**
Spring. 2 credits. Corequisite: CS 4120.]

**CS 4210 Numerical Analysis and Differential Equations (also MATH 4250)**
Fall. 4 credits. Prerequisites: MATH 2210 or 2940 or equivalent, one additional mathematics course numbered 3000 or above, and knowledge of programming.
For description, see MATH 4250.

**CS 4220 Numerical Analysis: Linear and Nonlinear Equations (also MATH 4260)**
Spring. 4 credits. Prerequisites: MATH 2210 or 2940 or equivalent, one additional mathematics course numbered 300 or above, and knowledge of programming.

**CS 4300 Information Retrieval (also INFO 4300)**
Fall. 3 credits. Prerequisite: CS 2110 or equivalent.
For description, see INFO 4300 in CIS section.

**CS 4302 Web Information Systems (also INFO 4302)**
Spring. 3 credits. Prerequisites: CS 2110 and some familiarity with web site technology.
For description, see INFO 4302 in CIS section.

**CS 4320 Introduction to Database Systems**
Fall. 3 credits. Prerequisites: CS 3110 (or CS 2110, 2111 and permission of instructor).

**CS 4321 Practicum in Database Systems**
Fall. 2 credits. Pre- or corequisite: CS 4320. CS majors may use only one of the following toward their degree: CS/INFO 3300 or CS 4321.

**CS 4410 Operating Systems**
Spring. 3 credits. Prerequisite: CS 3410 or 3420.

**CS 4411 Practicum in Operating Systems**
Spring. 2 credits. Corequisite: CS 4410.

**CS 4420 Computer Architecture (also ECE 4750)**
Fall. 4 credits. Prerequisites: ENGRD 2300 and CS 3420/ECE 3140.
For description, see ECE 4750.

**CS 4450 Computer Networks**
Spring. 4 credits. Pre- or corequisite: CS 4410 or permission of instructor.

**CS 4520 Introduction to Bioinformatics**
Spring. 4 credits. Prerequisites: CS/ENGRD 2110, CS 2800.

**CS 4620 Introduction to Computer Graphics (also ARCH 3704)**
Fall. 3 credits. Prerequisite: CS/ENGRD 2110.

**CS 4621 Computer Graphics Practicum**
Fall. 2 credits. Pre- or corequisite: CS 4620.

**CS 4700 Foundations of Artificial Intelligence**
Fall. 3 credits. Prerequisites: CS/ENGRD 2110 and CS 2800 or equivalent.

**CS 4701 Practicum in Artificial Intelligence**
Fall. 2 credits. Pre- or corequisite: CS 4700.

**CS 4702 Artificial Intelligence: Uncertainty and Multi-Agent Systems**
Spring. 4 credits. Prerequisites: CS/ENGRD 2110 and CS 2800 or equivalent.

**CS 4740 Introduction to Natural Language Processing (also COGST 4740, LING 4474)**
Spring. 4 credits. Prerequisite: CS 2110.

**[CS 4780 Machine Learning**
Spring. 4 credits. Prerequisites: CS 2111, CS 2800, or basic probability theory, and basic knowledge of linear algebra. Next offered 2009–2010.]

**CS 4782 Probabilistic Graphical Models (also BTRY 4790)**
Fall. 4 credits. Prerequisites: probability theory (BTRY 4080 or equivalent), programming and data structures (CS 2110 or equivalent); course in statistical methods recommended but not required (BTRY 4090 or equivalent).
For description, see BTRY 4790.

**[CS 4812 Quantum Computation (also PHYS 4481/7681)**
Spring. 2 credits. Prerequisite: familiarity with theory of vector spaces over complex numbers. Next offered 2009–2010.
For description, see PHYS 4481.]

**CS 4820 Introduction to Analysis of Algorithms**
Spring, summer. 4 credits. Prerequisites: CS 2800 and 3110.

**CS 4830 Introduction to Cryptography**
Fall. 4 credits. Prerequisites: CS 2800 (or equivalent), CS 3810 (or mathematical maturity), or permission of instructor.

**CS 4850 Mathematical Foundations for the Information Age**
Spring. 4 credits. Prerequisite: CS 3810.

**CS 4860 Applied Logic (also MATH 4860)**
Spring. 4 credits. Prerequisites: MATH 2220 or 2940, CS 2800 or equivalent (e.g., MATH 3320, 4320, 4340, 4810), and some additional course in mathematics or theoretical computer science.

**CS 4999 Independent Reading and Research**
Fall, spring. 1–4 credits.

**CS 5150 Software Engineering**
Spring. 4 credits. Prerequisite: CS 2110 or equivalent experience programming in Java or C++.

**CS 5300 The Architecture of Large-Scale Information Systems (also INFO 5300)**
Spring. 4 credits. Prerequisite: CS/INFO 3300 or 4320.
For description, see INFO 5300 in CIS section.

**CS 5410 Intermediate Computer Systems**
Fall or spring. 4 credits. Prerequisite: CS 4410 or permission of instructor. Next offered fall 2008.

**CS 5420 Parallel Computer Architecture (also ECE 5720)**
Fall. 4 credits. Prerequisite: ECE 4750.
For description, see ECE 5720.

**CS 5430 System Security**
Fall or spring. 4 credits. Prerequisites: CS 4410 or 4450 and familiarity with Java, C, or C# programming languages. Next offered spring 2009.

**CS 5450 Advanced Computer Networks**
Fall or spring. 4 credits. Prerequisites: CS 4450 or permission of instructor.

**[CS 5620 Interactive Computer Graphics**
Spring. 4 credits. Prerequisite: CS 4620. Next offered 2009–2010.]

**[CS 5640 Computer Animation (also ART 2703, CIS 5640)**
Fall. 4 credits. Prerequisite: none.
For description, see ART 2703. Next offered 2009–2010.]

**[CS 5642 Advanced Animation (also ART 3702, CIS 5642)**
Spring. 4 credits. Prerequisite: none.
For description, see ART 3702. Next offered 2009–2010.]

**CS 5643 Physically Based Animation for Computer Graphics**
Spring. 4 credits. Prerequisites: CS/ENGRD 3220 and/or CS 4620 or permission of instructor. Offered alternate years.

**[CS 5722 Heuristic Methods for Optimization (also CEE 5090, ORIE 5340)**
Fall. 3 or 4 credits. Prerequisites: CS/ ENGRD 2110 or 3220 or CEE/ENGRD 3200, or graduate standing, or permission of instructor. Next offered 2009–2010.
For description, see CEE 5290.]

**[CS 5780 Empirical Methods in Machine Learning and Data Mining**
Fall or spring. 4 credits. Prerequisites: CS 2800 and 3110 or equivalent. Next offered 2009-2010.]

**CS 5846 Decision Theory I (also ECON 4760/6760)**
Fall. 4 credits. Prerequisite: mathematical sophistication. For description, see ECON 4760.

**CS 6110 Advanced Programming Languages**
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.

**[CS 6210 Matrix Computations**
Fall. 4 credits. Prerequisites: MATH 4110 and 4310 or permission of instructor. Offered alternate years; next offered 2009–2010.]

**CS 6220 Sparse Matrix Computation**
Fall. 4 credits. Prerequisite: CS 6210. Offered alternate years.

**[CS 6240 Numerical Solution of Differential Equations**
Spring. 4 credits. Prerequisites: exposure to numerical analysis (e.g., CS 4210 or 6210), differential equations, and knowledge of MATLAB.]

**CS 6320 Database Systems**
Spring. 4 credits. Prerequisite: CS 4320 or permission of instructor.

**CS 6322 Advanced Database Systems**
Fall. 4 credits.

**CS 6410 Advanced Systems**
Fall or spring. 4 credits. Prerequisite: CS 4410 or permission of instructor. Next offered fall 2008.

**CS 6450 Research in Computer Networks**
Fall or spring. 4 credits. Prerequisite: CS 4450 or permission of instructor. Next offered fall 2008.

**[CS 6460 Peer-to-Peer Systems**
Spring. 4 credits. Recommended: CS 6410. Next offered 2009–2010.]

**CS 6522 Biological Sequence Analysis**
Fall. 4 credits. Prerequisite: none.

**CS 6620 Advanced Interactive Graphics**
Fall or spring. 4 credits. Prerequisite: CS 4620 and 4621 or 5620 or permission of instructor.

**[CS 6630 Realistic Image Synthesis**
Fall or spring. 4 credits. Prerequisites: CS 4620 or equivalent and undergraduate-level understanding of algorithms, programming, and vector calculus.]

**CS 6650 Computational Motion**
Fall. 4 credits. Prerequisites: Undergraduate-level understanding of algorithms, and some scientific computing. Offered alternate years.

**[CS 6670 Machine Vision**
Fall or spring. 4 credits. Prerequisites: undergraduate-level understanding of algorithms and MATH 2210 or equivalent. Next offered 2009–2010.]

**[CS 6700 Advanced Artificial Intelligence**
Spring. 4 credits. Prerequisites: CS 4700 or permission of instructor. Next offered 2009–2010.]

**CS 6740 Advanced Language Technologies (also INFO 6300)**
Fall or spring. 3 credits. Prerequisite: permission of instructor. Neither CS 4300 nor CS 4740 are prerequisites. Next offered fall 2008.

**[CS 6764 Reasoning about Knowledge**
Fall. 4 credits. Prerequisites: mathematical maturity and acquaintance with propositional logic. Next offered 2010–2011.]

**[CS 6766 Reasoning about Uncertainty**
Fall. 4 credits. Prerequisites: mathematical maturity and acquaintance with propositional logic. Next offered 2009–2010.]

**[CS 6780 Advanced Topics in Machine Learning**
Fall or spring. 4 credits. Prerequisites: CS 4780 or equivalent, or CS 5780 or equivalent, or permission of instructor. Next offered 2009–2010.]

**CS 6782 Probabilistic Graphical Models (also BTRY 6790)**
Fall. 4 credits. Prerequisites: probability theory (BTRY 4080 or equivalent), programming and data structures (CS 2110 or equivalent); a course in statistical methods is recommended but not required (BTRY 4090 or equivalent).

For description, see BTRY 6790.

**CS 6810 Theory of Computing**
Spring. 4 credits. Prerequisite: CS 3810 and CS 4820 or 6820 or permission of instructor.

**CS 6820 Analysis of Algorithms**
Fall. 4 credits. Prerequisite: CS 4820 or graduate standing.

**CS 6822 Advanced Topics in Theory of Computing**
Fall or spring. 4 credits. Prerequisite: CS 6820 or permission of instructor. Next offered spring 2009.

**CS 6830 Cryptography**
Fall. 4 credits. Prerequisites: general ease with algorithms and elementary probability theory, maturity with mathematical proofs (ability to read and write mathematical proofs).

**[CS 6840 Algorithmic Game Theory**
Fall or spring. 4 credits. Prerequisite: background in algorithms and graphs at level of CS 4820. No prior knowledge of game theory or economics assumed. Next offered 2009–2010.]

**CS 6850 The Structure of Information Networks (also INFO 6850)**
Fall or spring. 4 credits. Prerequisite: CS 4820.

**CS 7090 Computer Science Colloquium**
Fall, spring. 1 credit. For staff, visitors, and graduate students interested in computer science. S–U grades only.

**CS 7190 Seminar in Programming Languages**
Fall, spring. 4 credits. Prerequisite: CS 6110 or permission of instructor. S–U grades only.

**CS 7192 Seminar in Programming Refinement Logics**
Fall, spring. 4 credits. Prerequisite: permission of instructor.

**CS 7320 Topics in Database Systems**
Fall, spring. 4 credits. S–U grades only.

**CS 7390 Database Seminar**
Spring. 1 credit. S–U grades only. Prerequisite: CS 6322 or permission of instructor.

**CS 7410 Topics in Systems**
Fall or spring. 3 credits. Prerequisite: permission of instructor.

**CS 7490 Systems Research Seminar**
Fall, spring. 1 credit. S–U grades only.

**CS 7690 Computer Graphics Seminar**
Fall, spring. 3 credits.

**CS 7726 Evolutionary Computation and Design Automation (also MAE 6500)**
Fall. 4 credits. Prerequisite: programming experience or permission of instructor.

**CS 7790 Seminar in Artificial Intelligence**
Fall, spring. 4 credits. Prerequisite: permission of instructor. S–U grades only.

**CS 7794 Seminar in Natural Language Understanding**
Fall, spring. 2 credits.

**CS 7890 Seminar in Theory of Algorithms and Computing**
Fall, spring. 4 credits. Prerequisite: permission of instructor. S–U grades only.

**CS 7999 Independent Research**
Fall, spring. Prerequisite: permission of computer science advisor.

Independent research or master of engineering project.

**CS 9999 Thesis Research**
Fall, spring. Prerequisite: permission of computer science advisor. S–U grades only.

Doctoral research.

## EARTH AND ATMOSPHERIC SCIENCES

T. E. Jordan, chair; A. T. DeGaetano, associate chair (CALS); J. L. Cisne, director of undergraduate studies (Science of Earth Systems); R. W. Allmendinger, W. D. Allmon, C. Andronicos, M. Barazangi, L. D. Brown, L. M. Cathles, S. J. Colucci, K. H. Cook, A. T. DeGaetano, L. A. Derry, M. Goman, C. H. Greene, D. L. Hysell, R. W. Kay, S. Mahlburg Kay, R. Lohman, N. Mahowald, B. Monger, A. Moore, J. Phipps Morgan, M. Pritchard, S. J. Riha, W. M. White, D. S. Wilks, M. W. Wysocki

For complete course descriptions, see the Earth and Atmospheric Sciences listing in the College of Arts and Sciences or College of Agriculture and Life Sciences section.

**EAS 1101 Introductory Geological Sciences (To Know Earth)**
Fall. 3 credits. C. Andronicos.

**EAS 1108 Earth in the News**
Summer. 3 credits. S. L. Losh.

**EAS 1109 Dinosaurs**
Fall. 1 credit. J. L. Cisne.

**EAS 1190 Fossil Preparation**
Fall. 1 credit. Prerequisite: EAS 1109 or related EAS course. W. Allmon and J. Cisne.

**EAS 1220 Earthquake! (also ENGRI 1220)**
Spring. 3 credits. L. Brown.

Course in Introduction to Engineering series. For description, see ENGRI 1220.

**EAS 1310 Basic Principles of Meteorology**
Fall. 3 credits. 1-credit lab is EAS 1330. M. W. Wysocki.

**EAS 1330 Basic Meteorology Lab**
Fall. 1 credit. Corequisite: EAS 1310. M. W. Wysocki.
Covers topics presented in EAS 1310.

**EAS 1340 Special Topics in Atmospheric Science: Weather Analysis and Forecasting**
Spring. 1 credit. Prerequisites: EAS 1310 and EAS 1330. S–U grades only. M. W. Wysocki and staff.
This course will serve as an extension of the EAS 1330 first-year majors lab. It will provide opportunity for formal weather briefings, explore specific atmospheric storms (synoptic and mesoscale, including the climatology of each storm type), through assigned readings, map analysis, and weather discussions.

**EAS 1540 Introductory Oceanography (also BIOEE 1540)**
Fall, summer. 3 credits. Lec. Optional 1-credit lab is EAS/BIOEE 1550. Fall: C. Greene and B. Monger; summer: B. Monger.

**EAS 1550 Introductory Oceanography Lab (also BIOEE 1550)**
Fall. 1 credit. Lab. Corequisite: EAS/BIOEE 1540. C. Greene and B. Monger.
Laboratory course covering topics presented in EAS/BIOEE 1540.

**EAS 1700 Evolution of the Earth and Life (also BIOG 1700)**
Spring. 3 credits. J. L. Cisne.

**EAS 2130 Marine and Coastal Geology**
Summer. 4 credits. Prerequisite: introductory geology or ecology or permission of instructor. Staff.

**EAS 2200 The Earth System**
Fall, spring. 4 credits. Prerequisites: MATH 1110/1910. Letter grades only. W. M. White and A. Moore.

**EAS 2220 Seminar—Hawaii's Environment**
Fall. 1 credit. S–U grades only. A. Moore.

**EAS 2500 Meteorological Observations and Instruments**
Fall. 4 credits. Prerequisite: EAS 1310. M. W. Wysocki.

**EAS 2680 Climate and Global Warming**
Spring. 3 credits. Prerequisite: basic college math. S–U or letter grades. A. T. DeGaetano.

**EAS 2900 Computer Programming and Meteorology Software**
Spring, 3 credits. Prerequisites: EAS 1310; MATH 1110 or equivalent. N. Mahowald and B. Belcher.

**EAS 2960 Forecast Competition**
Fall and spring. 1 credit; students enroll for two consecutive semesters; credit awarded for second semester; may be repeated for credit. Prerequisite: sophomore standing in atmospheric science or permission of instructor. S–U grades only. D. S. Wilks.

**EAS 3010 Evolution of the Earth System**
Fall. 4 credits. Prerequisites: EAS 2200, MATH 1120 or 1920, and CHEM 2070 or equivalent. T. Jordan, S. Riha, and W. D. Allmon. Two Saturday field trips.

**EAS 3030 Introduction to Biogeochemistry (also NTRES 3030)**
Fall. 4 credits. Prerequisites: CHEM 2070 or equivalent, MATH 1120, plus a biology and/or geology course. L. A. Derry and J. Yavitt.

**EAS 3040 Interior of the Earth**
Spring. 3 credits. Prerequisite: EAS 2200 or permission of instructor. C. Andronicos.

**EAS 3050 Climate Dynamics**
Fall. 3 credits. Prerequisite: two semesters of calculus and one semester of physics. K. H. Cook.

**EAS 3220 Biogeochemistry of the Hawaiian Islands**
Spring. 4 credits. Prerequisite: enrollment in EES semester in Hawaii, EAS 2200, EAS 3030, or permission of instructor. L. A. Derry.

**[EAS 3340 Microclimatology**
Spring. 3 credits. Prerequisite: physics course. Next offered 2009–2010. D. S. Wilks.]

**EAS 3400 Field Study of the Earth System**
Spring. 6 credits. Prerequisites: enrollment in Earth and Environmental Sciences Semester in Hawaii; one semester of calculus (MATH 1910/1920 or 1110/1120 and two semesters of any of the following: PHYS 2207/2208 or 1112/2213; CHEM 2070/2080 or 2090/2080; BIOG 1101/1103–1102/1104 or 1105/1106 or 1109/1100; or equivalent course work. A. Moore.

**EAS 3410 Atmospheric Thermodynamics and Hydrostatics**
Fall. 3 credits. Prerequisites: one year of calculus and one semester of physics. A. T. DeGaetano.

**EAS 3420 Atmospheric Dynamics (also ASTRO 3342)**
Spring. 3 credits. Prerequisites: MATH 2930, 2130 or equivalent; one year physics. K. H. Cook.

**[EAS 3500 Dynamics of Marine Ecosystems (also BIOEE 3500)**
Fall. 3 credits. Prerequisites: one year of calculus and a semester of oceanography (e.g., EAS 1540), or permission of instructor. Offered alternate years; Next offered 2009–2010. C. H. Greene and R. W. Howarth.]

**EAS 3510 Marine Ecosystems Field Course (BIOEE 3510)**
Spring. 4 credits. Recommended: EAS 3400. C. H. Greene and C. D. Harvell.

**EAS 3520 Synoptic Meteorology I**
Spring. 3 credits. Prerequisite: EAS 3410. Corequisite: EAS 3420. M. W. Wysocki.

**EAS 3530 Physical Oceanography**
Fall. 3 credits. Prerequisites: MATH 1120 or 1920, or one year of physics, or permission of instructor. Offered alternate years. B. C. Monger.

**EAS 4010 Fundamentals of Energy and Mineral Resources**
Fall. 3 credits. Previous course in geology helpful but not necessary. L. Cathles.

**EAS 4040 Geodynamics**
Spring. 3 credits. Prerequisite: calculus and calculus-based physics course or permission of instructor. Offered alternate years. J. Phipps Morgan.

**[EAS 4050 Active Tectonics**
Spring. 3 credits. Recommended: mechanical background equivalent to EAS 4260/4880. S–U or letter grades. Offered alternate years; next offered 2009–2010. R. Lohman.]

**EAS 4170 Field Mapping in Argentina**
Summer. 3 credits. Prerequisites: introductory EAS course and EAS 4260 or EAS 3040. Offered alternate years. S. Mahlburg Kay.

**[EAS 4250 European Discovery of Impacts and Explosive Volcanism**
Spring. 2 credits. Prerequisite: junior, senior, or graduate students with background in geology and permission of instructor. One two-hour meeting per week plus field trip during spring break. Offered alternate years; next offered 2009–2010. J. Phipps Morgan.]

**EAS 4260 Structural Geology**
Spring. 4 credits. Prerequisite: one semester of calculus plus an introductory geology course or permission of instructor. One weekend field trip. Offered alternate years. C. Andronicos.

**EAS 4340 Exploration Geophysics**
Fall. 3 credits. Prerequisites: MATH 1920 and PHYS 2208, 2213, or equivalent. Offered alternate years. L. D. Brown.

**EAS 4350 Statistical Methods in Meteorology and Climatology**
Fall. 3 credits. Prerequisites: one introductory course each in statistics (e.g., AEM 2100) and calculus. D. S. Wilks.

**[EAS 4370 Geophysical Field Methods (also ARKEO 4370)**
Fall. 3 credits. Prerequisite: PHYS 2208 or 2213 or permission of instructor. Offered alternate years; next offered 2009–2010. L. D. Brown.]

**[EAS 4400 Seminar: Climate Science, Impacts and Mitigation**
Fall. 2 credits. Prerequisites: junior or higher standing. Offered alternate years; next offered 2009–2010. N. Mahowald.]

**[EAS 4470 Physical Meteorology**
Fall. 3 credits. Prerequisites: one year each of calculus and physics. Offered alternate years; next offered 2009–2010. A. T. DeGaetano.]

**EAS 4510 Synoptic Meteorology II**
Fall. 3 credits. Prerequisites: EAS 3410 and 3420. S. J. Colucci.

**EAS 4530 Mineralogy**
Fall. 4 credits. Prerequisites: EAS 1101 or 2200 and CHEM 2070 or 2090 or permission of instructor. S. Mahlburg Kay.

**[EAS 4540 Petrology and Geochemistry**
Spring. 4 credits. Prerequisite: EAS 4530. Next offered 2010–2011. R. W. Kay.]

**[EAS 4550 Geochemistry**
Fall. 4 credits. Prerequisites: CHEM 2070 or CHEM 2090 and MATH 1920 or equivalent. Recommended: EAS 3040. Offered alternate years; next offered 2009–2010. W. M. White.]

**[EAS 4560 Mesoscale Meteorology**
Spring. 3 credits. Prerequisites: EAS 3410 and 3420 or permission of instructor. Next offered 2009–2010. S. J. Colucci.]

**EAS 4570 Atmospheric Air Pollution**
Fall. 3 credits. Prerequisites: EAS 3410 or one course in thermodynamics, and one semester of chemistry, or permission of instructor. Offered alternate years. M. W. Wysocki.

**EAS 4580 Volcanology**
Fall. 3 credits. Prerequisite: EAS 3040 or equivalent. Offered alternate years. R. W. Kay.

**EAS 4600 Late Quaternary Paleoecology**
Fall. 4 credits. Offered alternate years. M. Goman.

**[EAS 4610 Paleoclimate: Since the Last Ice Age**
Fall. 3 credits. Prerequisite: EAS 2200 or permission of instructor. Offered alternate years; next offered 2009–2010. M. Goman.]

**EAS 4620 Marine Ecology (also BIOEE 4620)**
Fall. 3 credits. Limited to 75 students. Prerequisite: BIOEE 2610. Offered alternate years. C. D. Harvell and C. H. Greene.
For description, see BIOEE 4620.

**EAS 4700 Weather Forecasting and Analysis**
Spring. 3 credits. Prerequisites: EAS 3520 and 4510. M. W. Wysocki.

**[EAS 4710 Introduction to Groundwater Hydrology (also BEE 4710)**
Spring. 3 credits. Prerequisites: MATH 2940 and ENGRD 2020. Offered alternate years; next offered 2009–2010. L. M. Cathles and T. S. Steenhuis.]

**EAS 4750 Special Topics in Oceanography**
Fall, spring, summer. 2–6 credits, variable. Prerequisites: one semester of oceanography and permission of instructor. Fall, spring: C. H. Greene; summer: B. C. Monger.

**[EAS 4760 Sedimentary Basins**
Spring. 3 credits. Prerequisite: EAS 3010 or permission of instructor. Offered alternate years; next offered 2009–2010. T. E. Jordan.]

**EAS 4780 Advanced Stratigraphy**
Fall. 3 credits. Prerequisite: EAS 3010 or permission of instructor. Offered alternate years. T. E. Jordan.

**EAS 4790 Paleobiology (also BIOEE 4790)**
Spring. 4 credits. Prerequisites: one year introductory biology and either BIOEE 2740 or 3730 or EAS 3010, or permission of instructor. W. D. Allmon.

**EAS 4810 Survey of Earth Systems**
Fall, spring. 2 credits. Fall, R. Kay; spring, J. Cisne.

**EAS 4820 Atmospheric Modeling**
Spring. 3 credits. Prerequisite: differential equations, introductory computer background, junior standing or above or permission of instructor. S–U or letter grades. N. Mahowald.

**EAS 4830 Environmental Biophysics (also CSS 4830)**
Fall. 4 credits. Prerequisite: CSS 2600 or equivalent calculus. H. Van Es and S. J. Riha.

**EAS 4840 Inverse Methods in the Natural Sciences**
Fall. 3 credits. Prerequisite: MATH 2940. D. L. Hysell.

**EAS 4870 Introduction to Radar and Remote Sensing (also ECE 4870)**
Spring. 3 credits. Prerequisites: PHYS 2208 or 2213 or equivalent, or permission of instructor. D. L. Hysell.

**EAS 4880 Global Geophysics**
Spring. 3 credits. Prerequisites: MATH 1920 (or 1120) and PHYS 2080 or 2130. Offered alternate years; next offered 2009–2010. M. Pritchard and R. Lohman.

**EAS 4910–4920 Undergraduate Research**
Fall, spring. 1–4 credits. Students must complete form at 2124 Snee Hall. Staff (J. L. Cisne, coordinator).

**EAS 4940 Special Topics in Atmospheric Science (undergraduate level)**
Fall or spring. 8 credits max. S–U or letter grades. Staff.

**EAS 4960 Internship Experience**
Fall, spring. 2 credits. Prerequisite: Enrollment in EES semester in Hawaii and EAS 3400. S–U grades only. A. Moore.

**EAS 4970 Individual Study in Atmospheric Science**
Fall or spring. 1–6 credits. Students must register using independent study form. S–U grades only. Staff.

**EAS 4980 Teaching Experience in Earth and Atmospheric Sciences**
Fall or spring. 1–4 credits. Students must register using independent study form. S–U grades only. Staff.

**EAS 4990 Undergraduate Research in Atmospheric Science**
Fall, spring. Credit TBA. Students must register using independent study form. S–U grades only. Staff.

**EAS 5000 Design Project in Geohydrology**
Fall, spring. 3–12 credits. Alternative to industrial project for M.Eng. students choosing geohydrology option. May continue over two or more semesters. L. M. Cathles.

**EAS 5020 Case Histories in Groundwater Analysis**
Spring. 4 credits. L. M. Cathles.

**EAS 5050 Fluid Dynamics in the Earth Sciences**
Spring. 3 credits. Prerequisites: MATH through 2940, PHYS through 2208 or 2214, or permission of instructor. L. Cathles and M. Wysocki.

**EAS 5110 Measurement and Discovery**
Fall. 1 credit (S–U) or 2 credits (with paper, letter grades). Prerequisite: permission of instructor. J. L. Cisne.

**[EAS 5220 Advanced Structural Geology I**
Fall. 3 credits. Prerequisites: EAS 4260 and permission of instructor. Offered alternate years, next offered 2009–2010. R. W. Allmendinger and C. Andronicos.]

**[EAS 5240 Advanced Structural Geology II**
Fall. 3 credits. Prerequisites: EAS 4260 and permission of instructor. Offered alternate years; next offered 2009–2010. R. W. Allmendinger.
Geometry, kinematics, and mechanics of structural provinces.]

**[EAS 5530 Advanced Petrology**
Fall. 3 credits. Prerequisite: EAS 4540. Offered alternate years; next offered 2009–2010. R. W. Kay.]

**EAS 5750 Planetary Atmospheres (also ASTRO 6575)**
Fall. 4 credits. Prerequisites: undergraduate physics, vector calculus. Offered alternate years. P. Gierasch.

**EAS 5770 Planetary Surface Processes (also ASTRO 6577)**
Spring. 3 or 4 credits. Offered alternate years. J. Bell.

**EAS 5780 Planet Formation and Evolution (also ASTRO 6578)**
Fall. 4 credits. Prerequisites: familiarity with elementary physics and math or permission of instructor. Offered alternate years. J-L. Margot and M. Pritchard.
For description, see ASTRO 6578.

**EAS 5840 Inverse Methods in the Natural Sciences**
Fall. 3 credits. Prerequisite: MATH 2940. Complete substantial class project. D. L. Hysell.

**EAS 6280 Geology of Orogenic Belts**
Spring. 3 credits. Prerequisite: permission of instructor. S. M. Kay.

**EAS 6410 Analysis of Biogeochemical Systems**
Spring. 2 credits. Prerequisite: MATH 2930 or permission of instructor. Offered alternate years. L. A. Derry.

**EAS 6480 Air Quality and Atmospheric Chemistry (also MAE 6480)**
Fall. 3 credits. Prerequisites: first-year chemistry and thermodynamics (or equivalent) and fluid mechanics (or equivalent); graduate standing or permission of instructor. S–U or letter grades. K. M. Zhang.
For description, see MAE 6480.

**EAS 6520 Advanced Atmospheric Dynamics (also ASTRO 7652)**
Spring. 3 credits. Prerequisites: EAS 3410 and 3420 or equivalent. S. J. Colucci.

**EAS 6560 Isotope Geochemistry**
Spring. 3 credits. Open to undergraduates. Prerequisite: EAS 4550 or permission of instructor. Offered alternate years. W. M. White.

**EAS 6660 Applied Multivariate Statistics**
Spring. 3 credits. Prerequisites: multivariate calculus, matrix algebra, and two statistics courses. D. S. Wilks.

**EAS 6750 Modeling the Soil-Plant-Atmosphere System (also CSS 6750)**
Spring. 3 credits. Prerequisite: EAS/CSS 4830 or equivalent. S. J. Riha.

**EAS 6920 Special Topics in Atmospheric Science**
Fall, spring. 1–6 credits. S–U or letter grades. Staff.

**EAS 6930 Special Topics in Geological Sciences**
Fall or spring. 1–3 credits, variable. S–U or letter grades. Staff.

**EAS 7000–7990 Seminars and Special Work**
Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.

**EAS 7010–7020 Thesis Research**
7010, fall; 7020, spring. 1–15 credits, variable. S–U or letter grades. Staff.

**EAS 7110 Upper Atmospheric and Space Physics**
Fall or spring. 1–6 credits. D. L. Hysell. Seminar.

**EAS 7220 Advanced Topics in Structural Geology**
R. W. Allmendinger.

**EAS 7310 Advanced Topics in Remote Sensing and Geophysics**
M. Pritchard.

**EAS 7330 Advanced Topics in Geodynamics**
Spring. J. Phipps Morgan.

**EAS 7500 Satellite Remote Sensing in Biological Oceanography**
Summer. 3 credits. B. C. Monger.

**EAS 7510 Petrology and Geochemistry**
R. W. Kay.

**EAS 7550 Advanced Topics in Tectonics and Geochemistry**
Fall. 3 credits. J. Phipps Morgan.

**EAS 7570 Current Research in Petrology and Geochemistry**
S. Mahlburg Kay.

**EAS 7620 Advanced Topics in Paleobiology**
W. D. Allmon.

**EAS 7710 Advanced Topics in Sedimentology and Stratigraphy**
T. E. Jordan.

**EAS 7730 Paleobiology**
J. L. Cisne.

**EAS 7750 Advanced Topics in Oceanography**
C. H. Greene.

**EAS 7800 Earthquake Record Reading**
Fall. M. Barazangi.

**EAS 7810 Exploration Geophysics**
L. D. Brown.

**EAS 7930 Andes-Himalaya Seminar**
S. Mahlburg Kay, R. W. Allmendinger, M. Pritchard, and T. E. Jordan.

**EAS 7950 Low-Temperature Geochemistry**
1–3 credits. S–U grades only. L. A. Derry.

**EAS 7960 Geochemistry of the Solid Earth**
W. M. White.

**EAS 7970 Fluid-Rock Interactions**
L. M. Cathles.

**EAS 7990 Soil, Water, and Geology Seminar**
Spring. L. M. Cathles and T. S. Steenhuis.

**EAS 8500 Master's-Level Thesis Research in Atmospheric Science**
Fall, spring. Credit. S–U grades only. Graduate faculty.
Thesis research for atmospheric science master's students.

**EAS 9500 Graduate-Level Dissertation Research in Atmospheric Science**
Fall, spring. Credit. S–U or letter grades. Graduate faculty.
Dissertation research for atmospheric science Ph.D. students only before "A" exam has been passed.

**EAS 9510 Doctoral-Level Dissertation Research in Atmospheric Science**
Fall, spring. Credit. S–U or letter grades. Graduate faculty.
Dissertation research for atmospheric science Ph.D. candidates after "A" exam has been passed.

## ELECTRICAL AND COMPUTER ENGINEERING

C. R. Pollock, Director; T. L. Fine, Assoc. Director; D. F. Delchamps, Advising Coordinator; E. Afshari, D. H. Albonesi, A. B. Apsel, S. Bhave, A. W. Bojanczyk, H.-D. Chiang, P. Doerschuck, L. F. Eastman, T. L. Fine, W. K. Fuchs, Z. J. Haas, D. A. Hammer, S. S. Hemami, C. R. Johnson, Jr., E. Kan, M. C. Kelley, P. M. Kintner, R. R. Kline, A. Lal, M. Lipson, R. Manohar, J. F. Martínez, S. A. McKee, A. Molnar, F. Rana, A. P. Reeves, A. Scaglione, C. E. Seyler, J. R. Shealy, E. G. Sirer, M. G. Spencer, G. E. Suh, K. Tang, R. J. Thomas, S. Tiwari, L. Tong, A. B. Wagner, S. B. Wicker

**ECE 2100 Introduction to Circuits for Electrical and Computer Engineers (also ENGRD 2100)**
Fall, spring. 4 credits. Corequisites: MATH 2930 and PHYS 2213. All students must enroll in a lab and a sec.
For description, see ENGRD 2100.

**ECE 2200 Signals and Information**
Spring. 4 credits. Prerequisite: MATH 2930. All students must enroll in a lab and a sec.
Introduction to signal processing. Topics include frequency-based representations: Fourier series and discrete Fourier transform; discrete time linear systems: input/output relationships, filtering, spectral response; analog-to-digital and digital-to-analog conversion; continuous time signals and linear time invariant systems: frequency response and continuous-time Fourier transform.

**ECE 2300 Introduction to Digital Logic Design (also ENGRD 2300)**
Fall, spring. 4 credits. Prerequisite: CS 1110 or 1112.
For description, see ENGRD 2300.

**ECE 2500 Technology in Society (also ENGRG/HIST 2500, STS 2501)**
Fall. 3 credits. Humanities elective for engineering students.
For description, see ENGRG 2500.

**ECE 2910–2920 Sophomore Electrical and Computer Engineering Independent Project**
2910, fall; 2920, spring. 1–8 credits.
Individual study or directed reading in connection with a special engineering problem chosen by the student, after consultation with the faculty member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor and submit an Independent Project Form to the Student Services Office, 223 Phillips Hall.

**ECE 2930–2939; 2940–2949 Sophomore Electrical and Computer Engineering Group Projects**
2930–2939, fall; 2940–2949, spring. 1–8 credits.
Group study, analysis, and, usually, experimental tests in connection with a special engineering project chosen by the students after consultation with the faculty member directing the project. New projects will be added upon faculty request. Written progress reports are required. Students must submit a Group Project Form to the Student Services Office, 223 Phillips Hall.

**ECE 2980 Inventing an Information Society (also AMST/ENGRG 2980, HIST 2920, INFO 2921, STS 2921)**
Spring. 3 credits. Approved for humanities distribution.
For description, see ENGRG 2980.

**ECE 3030 Electromagnetic Fields and Waves**
Fall, summer. 4 credits. Prerequisites: grade of C or better in: PHYS 2213, PHYS 2214, MATH 2930, MATH 2940, and ECE/ENGRD 2100.
Covers static, quasi-static, and dynamic electromagnetic fields and waves. Topics include Maxwell's equations (integral and differential forms), fields of charge and current distributions, boundary conditions, fields near conductors, method of images, material polarization and dielectrics; energy, work, and power in electromagnetic systems; wave propagation and polarization, waves in media (dielectrics, conductors, and anisotropic materials); reflection, transmission, and refraction at media interfaces; guided waves in transmission lines, Smith charts, transients; metallic and dielectric waveguides; radiation and antennas, antenna arrays, electric circuits for transmission and reception, aperture antennas and diffraction.

**ECE 3060 Introduction to Quantum and Statistical Physics**
Fall. 4 credits. Prerequisites: PHYS 2214, MATH 2940, and ECE 3150 or co-registration.
Introductory quantum, statistical, and solid-state physics concepts necessary for understanding modern solid-state electronic and optical devices. Topics include the formalism and methods of quantum mechanics, structures of atoms, molecules, and solids and their interactions with electromagnetic waves, statistical physics, and the basic physics of semiconductor.

**ECE 3100 Introduction to Probability and Random Signals**
Fall, summer. 4 credits. Prerequisite: MATH 2940. May be used in place of ENGRD 2700 to satisfy engineering distribution requirement.
Introduction to the theory of probability as a basis for modeling random phenomena and signals, calculating the response of systems, and making estimates, inferences, and decisions in the presence of chance and uncertainty. Applications are given in such areas as communications, device modeling, and information theory. Material includes:

classical probability, probability measures, countable and uncountable sample spaces, random variables, probability mass function, probability density function, cumulative distribution function, important discrete and continuous distributions, functions of one random variable, functions of two random variables, random multivariate functions, moments, independence and correlation, conditional probability, characteristic functions, special characteristics of Normal distribution, signals and filtering, Central Limit Theorem, Law of Large Numbers, introduction to Decision and Estimation.

**ECE 3110 Electrical and Computer Engineering Honors Seminar**

Spring. 1 or 2 credits.

Students are required to attend all the lectures. Honors students must take this seminar for letter grade and 2 credits. Two summary papers are required. Nonhonors students must take the seminar pass/fail and for 1 credit. One summary paper is required. Summary papers review a topic presented in the seminar.

**ECE 3130 Computerized Instrumentation Interface Design**

Summer. 3 credits. Prerequisites: ECE 2100, and/or ECE/ENGRD 2300, and/or programming at the level of CS 2110. Can be used for ECE students as an Outside ECE Technical Elective or College Approved Elective (with advisor approval).

This course will explore the technologies for performing both speech recognition and computer-activated control through custom interface circuitry. Use will be made of commercial as well as custom software and hardware. Students will be expected to implement several methods in the programming languages C or JAVA. This is a team-oriented product development experience. Students will define the requirements of a product (a speech-controlled CD player) and organize into a development team according to their specialty knowledge skill sets. Application-oriented computer programming, digital interface circuit design, analog amplifiers and filters, are important to the project. This course spans the two coop sessions. The system level planning and basic component and module testing is completed in the first term, and the final construction and system integration will occur in the second half. Students are required to complete both sessions for a grade.

**ECE 3140 Computer Organization (also CS 3420)**

Spring. 4 credits. Prerequisite: CS/ENGRD 2110 or ENGRD 2300.

Topics include performance metrics, data formats, instruction sets, addressing modes, computer arithmetic, microcoded and pipelined datapath design, memory hierarchies including caches and virtual memory, I/O devices, bus-based I/O systems. Students learn assembly language programming and design a simple pipelined processor.

**ECE 3150 Introduction to Microelectronics**

Spring. 4 credits. Prerequisite: ECE/ENGRD 2100.

The course offers an introduction to the basic devices and circuits in modern microelectronics. Students will learn not only basic structures and operations of semiconductor devices through simple models (diodes, CMOS and BJT), but also how to analyze and design basic transistor modules in digital and analog circuits including biasing, amplifiers, filters, logic gates, and memory. We will introduce intuitive design methods to map circuit specifications to transistor topology, as well as first-order time-constant estimation. SPICE and measurement labs will accompany the progress in lectures for hands-on experiences.

**[ECE 3200 Networks and Systems**

Fall. 4 credits. Prerequisites: ECE 2200 and MATH 2940. Next offered 2009–2010.

Students develop a working understanding of the analytical and computational tools used in the design and representation of complex networks and systems. Topics include state-space techniques, finite state machines, graph-theoretic approaches to network design and analysis, complexity, phase transitions in complex systems, and scalability.]

**ECE 3250 Fundamental ECE Mathematics**

Fall. 3 credits. Prerequisites: MATH 2930, MATH 2940, and ECE 2200 or permission of instructor.

Course aims to deepen students' working knowledge of mathematical tools relevant to ECE applications. While the course emphasizes fundamentals, it also provides an ECE context for the topics it covers, which include foundational material about sets and functions; linear algebra; inner products and orthogonal representations; basic ideas from multivariable calculus; and elementary convex analysis.

**ECE 3910–3920 Junior Electrical and Computer Engineering Independent Project**

3910, fall; 3920, spring. 1–8 credits.

For description, see ECE 2910–2920.

**ECE 3930–3939; 3940–3949 Junior Electrical and Computer Engineering Group Project**

3930–3939, fall; 3940–3949. spring. 1–8 credits.

For description, see ECE 2930–2939; 2940–2949.

**ECE 4070 Physics of Semiconductors and Nanostructures**

Spring. 4 credits. Prerequisites: ECE 3060 or AEP 3610 and AEP 4230.

This course covers basic solid state and semiconductor physics relevant for understanding electronic and optical devices. Topics include crystalline structures, bonding in atoms and solids, energy bands in solids, electron statistics and dynamics in energy bands, effective mass equation, carrier transport in solids, Boltzmann transport equation, semiconductor homo- and hetero-junctions, optical processes in semiconductors, electronic and optical properties of semiconductor nanostructures, semiconductor quantum wells, wires, and dots, electron transport in reduced dimensions, semiconductor lasers and optoelectronics, high frequency response of electrons in solids and plasmons.

**ECE 4110 Random Signals in Communications and Signal Processing**

Fall. 4 credits. Prerequisite: ECE 2200 and ECE 3100 or equivalent.

Introduction to models for random signals in discrete and continuous time; Markov chains, Poisson process, queuing processes, power spectral densities, Gaussian random process. Response of linear systems to random signals. Elements of estimation and inference as they arise in communications and digital signal processing systems.

**ECE 4130 Introduction to Nuclear Science and Engineering (also MAE 4580, TAM 4130)**

Fall. 3 credits. Prerequisites: PHYS 2214 and MATH 2940.

For description, see TAM 4130.

**ECE 4150 GPS: Theory and Design (also MAE 4150)**

Fall. 4 credits. Culminating design experience (CDE) course. Prerequisite: a 3000-level engineering course with advanced math content (e.g., ECE 3030 or MAE 3260).

Analysis of GPS operating principles and engineering practice with a culminating design exercise. Navigational algorithms, receiver analysis, error investigation, dilution of precision, antennas, differential GPS.

**ECE 4210 Signal Processing Algorithms in Support of Painting Analysis**

Fall. 3 credits. Prerequisites: ECE 2200 and MATH 2940. Recommended. ECE 3250.

The analysis of fine art paintings by art historians and conservation specialists involves the close examination of various images (e.g., visible light, x-ray) of the painting. This course will focus on the paintings of Vincent Van Gogh and highlight case studies of recent technical examinations. The signal processing tasks encountered will be extracted and rudimentary solutions proposed based on fundamental signal processing techniques. Students will assess and improve these "starter" schemes, performing (a) periodicity extraction (e.g., for canvas thread counting), (b) set membership discrimination (e.g., for artist identification), and (c) multiple image alignment (e.g., for x-ray stitching). In this emerging application for signal processing, several of these tasks have no widely adopted computer-assisted schemes. MATLAB will be used for implementation of the algorithms on high resolution image data provided by the Van Gogh Museum (Amsterdam, the Netherlands).

**ECE 4250 Digital Signal Processing**

Fall. 4 credits. Prerequisites: ECE 2200 and 3100.

Introduces statistical signal processing. Signal representation and manipulation are covered via correlation and using the DFT/FFT to estimate other transforms; applications of these topics are then covered, including quantization, quantization effects in digital filters, multirate DSP, filter banks, delta-sigma modulation, power spectrum estimation, and introductions to Wiener and Kalman filtering and image processing.

**ECE 4260 Applications of Signal Processing**

Spring. 4 credits. Culminating Design Experience (CDE) course. Prerequisite: ECE 4250 or permission of instructor.

Applications of signal processing, including signal analysis, filtering, and signal synthesis. The course is laboratory oriented, emphasizing individual student projects. Design is done with signal-processing hardware and by computer simulation. Topics include filter design, spectral analysis, speech coding, speech processing, digital recording, adaptive noise cancellation, and digital signal synthesis.

**ECE 4300 Lasers and Optical Electronics**
Fall. 4 credits. Prerequisite: ECE 3030 or equivalent.
Introduction to the operation and application of lasers. Cover diffraction-limited optics, Gaussian beams, optical resonators, interaction of radiation with matter, physics of laser operation, and laser design. Discusses applications of coherent radiation to nonlinear optics, communication, and research.

**ECE 4320 MicroElectro Mechanical Systems (MEMS)**
Fall. 4 credits. Prerequisite: ECE 3150 or permission of instructor.
Introduction to MEMS: microsensors, microactuators, and microrobots. Fundamentals of MEMS, including materials, microstructures, devices and simple microelectro-mechanical systems, scaling electronic and mechanical systems to the micrometer/nm-scale, material issues, and the integration of micromechanical structures and actuators with simple electronics. This is an interdisciplinary course drawing content from mechanics, materials, structures, electronic systems, and the disciplines of physics and chemistry.

**ECE 4330 Microwave Theory, Devices, and Applications**
Fall. 4 credits. Prerequisite: ECE 3030.
Introduction to the properties of microwave devices and their applications in circuits, waveguides, resonators, and antennas. The course will cover the considerations that must be appreciated when the operating frequency approaches or exceeds 1GHz. Topics include microwave devices, microwave measurement techniques, S-parameters, signal flow diagrams, matching networks, basic circuit design considerations, and computer-aided device and circuit analysis. The course emphasizes physical understanding and intuitive design methods. Labs cover basic measurement techniques for active and passive elements as well as low noise amplifier design.

**ECE 4370 Fiber and Integrated Optics**
Spring. 4 credits. Culminating design experience (CDE) course. Prerequisite: ECE 3030 or equivalent.
Physical principles of optical waveguides. Wave equation solutions to the mode structure in waveguides, numerical analysis, mode coupling, dispersion and bandwidth limitations, optical materials, photonic band gap structures. Project design of planar optical components.

**ECE 4450 Computer Networks and Telecommunications**
Fall. 4 credits. Prerequisites: ECE 3140 or CS 3420 and a course in probability.
Design, analysis, and implementation of computer and communication networks and systems. This is a basic course in networking. Examples of topics that are covered include data transmission and data encoding, data link control, circuit vs. packet switching, Asynchronous Transfer Mode, local area network technology, network interconnections, protocol design (OSE and IP), network security, and multimedia. Emphasis is placed on performance evaluation.

**ECE 4510 Electric Power Systems I**
Fall. 4 credits. Prerequisite: ECE 3200 or equivalent.
Acquaints students with modern electric power system analysis and control. Stresses analysis techniques appropriate for the restructured industry and advanced protection and control systems. Topics include transmission line models, transformers and per unit system, generator models, network matrices, power flow, system protection, computer relaying, and GPS-based measurement and control systems.

**ECE 4520 Electric Power Systems II**
Spring. 4 credits. Prerequisite: ECE 3200 or permission of instructor.
Acquaints students with modern electric power system operation and control. Explores aspects of the restructuring of the industry and its implications for planning and operation objectives and methods. Topics include unit commitment, economic dispatch, optimal power flow, control of generation, system security and reliability, state-estimation, analysis of system dynamics, and system protection.

**ECE 4530 Analog Integrated Circuit Design**
Fall. 4 credits. Culminating design experience (CDE) course. Prerequisite: ECE 3150 or equivalent.
Overview of devices available to analog integrated-circuit designers in modern CMOS and BiCMOS processes: resistors, capacitors, MOS transistors, and bipolar transistors. Basic building blocks for linear analog integrated circuits: single-stage amplifiers, current mirrors, and differential pairs. Transistor-level design of linear analog integrated circuits, such as operational amplifiers and operational transconductance amplifiers. Layout techniques for analog integrated circuits. Throughout the course, emphasis is placed on design-oriented analysis techniques.

**ECE 4570 Silicon Device Fundamentals**
Fall. 4 credits. Prerequisites: ECE 3150 and 3060 or MSE 2620 or AEP 4500.
The course teaches fundamental principles on semiconductor carrier statistics, band diagrams, pn-junction diodes, heterojunctions, Schottky diodes, BJT, MOS capacitor and MOSFET. Emphasis is put on the MOSFET designs for advanced VLSI technology from its physical structure, accurate modeling, manufacturability and applications. Device designs will include short channel effects, gate-stack alternatives, band engineering, and strain engineering. By using computer simulation and experimental data, the course will culminate in a design project dealing with technical concerns in current VLSI industry. The goal for this course is to train circuit, device, and process engineers for semiconductor technology research and development.

**[ECE 4670 Digital Communication Receiver Design**
Fall. 4 credits. Culminating design experience (CDE) course. Prerequisite: ECE 2200. Next offered 2009–2010.
Introduction to broadband digital receiver design. Topics include PAM and QAM modulation and down-conversion, pulse-shaping, matched filtering, carrier frequency and phase recovery, baud-timing synchronization, packet marker synchronization, adaptive linear equalization, and coding. Course project: composition and testing of a MATLAB–based software receiver.]

**[ECE 4680 Telecommunication Systems**
Spring. 4 credits. Prerequisite: ECE 4670 or permission of instructor. Recommended: ECE 4110. Next offered 2009–2010.
Quadrature amplitude modulation receiver design, including I/Q mismatch compensation, carrier recovery (using Costas loop and phase-locked loop), baud-timing (using bandedge power optimization), and adaptive equalization (trained, blind, fractionally spaced, and using decision-feedback).]

**ECE 4720 Feedback Control Systems (also CHEME 4720, MAE 4780)**
Fall, spring. 4 credits. Prerequisites: CHEME 3720, ECE 2200, MAE 3260, or permission of instructor.
For description, see MAE 4780.

**ECE 4740 Digital VLSI Design**
Spring. 4 credits. Prerequisite: ECE 3150.
Introduction to digital VLSI design. Topics include basic transistor physics, switching networks and transistors, combinational and sequential logic, latches, clocking strategies, domino logic, PLAs, memories, physical design, floor planning, CMOS scaling, and performance and power considerations, etc. Lecture and homework topics emphasize disciplined design, and include: CMOS logic, layout, and timing; computer-aided design and analysis tools; and electrical and performance considerations.

**ECE 4750 Computer Architecture (also CS 4420)**
Fall. 4 credits. Culminating design experience (CDE) course. Prerequisites: ENGRD 2300 and ECE 3140/CS 3420.
Topics include instruction set principles, advanced pipelining, data and control hazards, multi-cycle instructions, dynamic scheduling, out-of-order execution, speculation branch prediction, instruction-level parallelism, and high-performance memory hierarchies. Students learn the issues and trade-offs involved in the design of modern microprocessors. Labs involve the design of a processor and cache subsystem at the RTL level.

**ECE 4760 Digital Systems Design Using Microcontrollers**
Spring. 4 credits. Culminating design experience (CDE) course. Prerequisite: ECE 3140/CS 3420. ECE 3150 highly recommended.
Design of real-time digital systems using microprocessor-based embedded controllers. Students working in pairs design, debug, and construct several small systems that illustrate and employ the techniques of digital system design acquired in previous courses. The content focuses on the laboratory work. The lectures are used primarily for the introduction of examples, description of specific modules to be designed, and instruction in the hardware and high-level design tools to be employed.

**ECE 4820 Plasma Processing of Electronic Materials (also MSE 4820)**
Spring. 3 credits. Prerequisites: PHYS 2213 and 2214 or equivalents. Offered if sufficient demand.
Fundamental principles that govern partially ionized, chemically reactive plasma discharges and their applications to processing electronic materials. Topics include simple models of low pressure, partially ionized plasmas, collision phenomena, diffusive processes, plasma chemistry and surface processes. Examples and their applications to electronic materials processing are discussed in detail.

**ECE 4840 Introduction to Controlled Fusion: Principles and Technology (also MAE 4590, NSE 4840)**

Spring. 3 credits. Prerequisites: PHYS 1112, 2213, and 2214, or equivalent background in electricity and magnetism and mechanics. Intended for seniors and graduate students in engineering and physical sciences.

Introduction to the physical principles and various engineering aspects underlying power generation by controlled fusion. Topics include: fuels and conditions required for fusion power and basic fusion-reactor concepts; fundamental aspects of plasma physics relevant to fusion plasmas and basic engineering problems for a fusion reactor; and an engineering analysis of proposed magnetic and/or intertial confinement fusion-reactor designs.

**ECE 4870 Introduction to Radar and Remote Sensing (also EAS 4870)**

Fall. 3 credits. Prerequisites: ECE 2200 and 4860 (or grade of B or better in ECE 3030).

For description, see EAS 4870 in the College of Arts and Sciences.

**ECE 4880 Radio Frequency (RF) Circuits and Systems**

Spring. 4 credits. Prerequisite: ECE 3150 or equivalent.

Basic RF circuits and applications. Receivers, transmitters, modulators, filters, detectors, transmission lines, oscillators, frequency synthesizers, low-noise amplifiers. Applications include communication systems, radio and television broadcasting, radar, radio, and radar astronomy. Computer-aided circuit analysis. Six laboratory sessions.

**ECE 4910–4920 Senior Electrical and Computer Independent Engineering Project**

4910, fall; 4920, spring. 1–8 credits.

For description, see ECE 2910–2920.

**ECE 4930–4939; 4940–4949 Senior Electrical and Computer Engineering Group Project**

4930–4939, fall; 4940–4949, spring. 1–8 credits.

For description, see ECE 2930–2939; 2940–2949.

**ECE 4950–4990 Special Topics in Electrical and Computer Engineering**

Spring, fall. 1–4 credits.

Seminar, special interest, or temporary course.

**ECE 5020 Biomedical System Design (also BME 5020)**

Spring. 4 credits. Co- or prerequisites: at least one of: ECE 4250, 4760, 4530.

Introduces techniques of measuring and conditioning low-level (biological) signals. Topics include special signal to noise improvement circuits for analog signals, techniques to remove common-mode and correlated noise, and computer-aided techniques for analyzing sampled data. Final six or seven weeks devoted to designing/prototyping a safe and effective "ambulatory microprocessor-controlled blood pressure monitor." Formal design document is required.

**ECE 5120 Applied Systems Engineering I (also CEE/CS 5040, MAE 5910, ORIE 5120, SYSEN 5100)**

Fall. 3 credits. Prerequisites: senior or graduate standing in engineering field; concurrent or recent (past two years) enrollment in group-based project with strong system design component approved by course instructor.

For description, see MAE 5910.

**ECE 5130 Applied Systems Engineering II (also CEE/CS 5050, MAE 5920, ORIE 5130, SYSEN 5200)**

Spring. 3 credits. Prerequisite: CEE 5240/CS 5040, ECE/ORIE 5120, or MAE 5910.

For description, see MAE 5920.

**ECE 5180 Principles of Medical Imaging (also VTMED 6180, BME 6180)**

Fall. 1–3 credits. Prerequisites: 3-credit enrollment requires functional knowledge and skills of linear algebra, calculus, Fourier transformation, and calculus-based physics.

For description, see BME 6180.

**ECE 5210 Theory of Linear Systems (also MAE 5210)**

Fall. 3 credits. Prerequisite: MAE 3260, ECE 3200, or permission of instructor. Recommended: good background in linear algebra and linear differential equations.

For description, see MAE 5210.

**[ECE 5310 Applied Quantum Optics for Photonics and Optoelectronics**

Spring. 4 credits. Prerequisites: ECE 3060 and 4070, or PHYS 4443. Next offered 2009–2010.

Introduces the basic concepts of quantum optics and quantum electronics necessary for understanding the behavior of optical fields in photonic and optoelectronic devices and systems. Topics include quantization of the electromagnetic field, quantum mechanical properties of photon states, vacuum fluctuations, noise and quantum Langevin equations, matter-photon interactions, phase-sensitive and phase-insensitive optical amplifiers, direct and coherent photon detection, lasers, parametric oscillators, and photonic devices for quantum information processing.]

**ECE 5330 Semiconductor Lasers**

Fall. 4 credits. Prerequisites: ECE 4300, ECE 4570, or permission of instructor.

Study of principles and characteristics of semiconductor lasers. Topics cover laser dynamics, noise, quantum confined structures, single-frequency lasers, traveling-wave lasers, surface-emitting lasers, reliability, and emerging research subjects. A term project and paper are required.

**ECE 5350 Semiconductor Physics**

Fall. 4 credits. Prerequisites: ECE 4070 and 4570, or permission of instructor. Offered alternate years from ECE 5370.

Physics of materials and structures useful in semiconductor electronic and photonic devices, including crystal structure, energy bands, effective mass, phonons, classical low-field transport, high-field and ballistic charge carrier transport, electron scattering by phonons, optical absorption, reflection, optical emissions, deep levels as charge carrier traps, and surface and interface effects.

**ECE 5360 Nanofabrication of Semiconductor Devices (also MSE 5410)**

Fall. 4 credits. Prerequisites: ECE 3150 and ECE 4570 or equivalent.

Introduction to modern nanofabrication technologies used to produce integrated circuits. Students perform a series of fabrication steps including lithography, metallization, plasma etching and annealing to realize working semiconductor devices (Schottky diodes, pn junction diodes, MOS capacitors, and MOSFETs) in the lab. Prior knowledge of the operation of these devices is essential as each will be tested to verify the success (or failure) of the fabrication process.

**[ECE 5370 Nanoscale Devices, Circuits, and Physics**

Fall, 4 credits. Prerequisites: ECE 4570 or permission of instructor. Offered alternate years from ECE 5350; next offered 2009–2010.

An integrated study connecting semiconductor physics with properties of electronic and optic devices at the nanoscale and the use of electronic devices in circuits. Topics include electronic and optic phenomena in confined structures and in nanoscale limits – single electron phenomena, nanoscale quantum and size effects such as in tunneling and optical transitions , transistor operation in limited scattering limits, plasmonics, molecular transport, interface effects, and the unification of device attributes with implementation in circuits.]

**ECE 5470 Computer Vision**

Fall. 4 credits. Prerequisites: ECE 2200 (or CS 2800 and 3420) or permission of instructor.

Covers computer acquisition and analysis of image data with emphasis on techniques for robot vision. Concentrates on descriptions of objects at three levels of abstraction: segmented images (images organized into subimages that are likely to correspond to interesting objects), geometric structures (quantitative models of image and world structures), and relational structures (complex symbolic descriptions of images and world structures). The programming of several computer-vision algorithms is required.

**[ECE 5480 Digital Image Processing**

Spring. 4 credits. Prerequisites: ECE 4110, ECE 4250, and familiarity with linear algebra. Next offered 2009–2010.

Introduction to image processing through seven major topics: perception, statistical modeling, transforms, enhancement, analysis, compression, and restoration. Special attention is allocated to compression. Equal emphasis is placed on gaining a mathematical and an intuitive understanding of algorithms through actual image manipulation and viewing.]

**ECE 5540 Advanced Analog VLSI Circuit Design**

Spring. 4 credits. Prerequisite: ECE 4530.

Advanced analog integrated circuit and system design. Topics include integrated continuous-time filter design, translinear circuits and systems, dynamic analog techniques, integrated discrete-time filter design, and Nyquist-rate data converter design.

**ECE 5580 Compound Semiconductor Electronics**

Spring. 3 or 4 credits; 4 with a project. Prerequisite: ECE 4570 or equivalent.

Electronic properties of advanced semiconductor structures using compound semiconductor materials and heterojunctions. Fundamentals of carrier transport and scattering. Properties of direct bandgap semiconductors and quantum wells. Advanced semiconductor devices, including metal-semiconductor transistors (FETs), modulation-doped FETs, and heterojunction bipolar transistors (HBTs). High-frequency operation of compound semiconductor devices. Includes six two-week labs, which include low-temperature carrier transport, optical absorption and emission, and electrical characterization of compound semiconductor devices.

**ECE 5620 Fundamental Information Theory**

Spring. 4 credits. Prerequisite: ECE 4110 or equivalent.

Fundamental results of information theory with application to storage, compression, and transmission of data. Entropy and other information measures. Block and variable-length codes. Channel capacity and rate-distortion functions. Coding theorems and converses for classical and multiterminal configurations. Gaussian sources and channels.

**[ECE 5640 Detection and Estimation**

Spring. 4 credits. Prerequisites: ECE 3100, 4110, or permission of instructor. Next offered 2009–2010.

Graduate-level introduction to fundamentals of signal detection and estimation with applications in communications. Elements of decision theory. Sufficient statistics. Signal detection in discrete and continuous time. Multiuser detection. Parameter estimations. Applications in wireless communications.]

**ECE 5660 Fundamentals of Networks**

Fall. 4 credits. Prerequisite: ECE 3100 or equivalent course in probability.

Introductory course on tools and techniques for modeling communication networks, synthesis of network protocols, analysis of network protocols' operation, and performance evaluation of network protocols when deployed in a particular communication network. Analytical tools include advanced probability theory, discrete and continuous-time Markov Chains, queuing theory, and graph theory. Simulation methods and statistical tools for analysis of data obtained from simulation models are studied. The basic mechanisms used in designing communication protocols in wireless and wired networks are illustrated by examples from numerous practical systems. Discussions of some classical papers help students learn about best practices as well as common mistakes occurring in studies of communication networks.

**ECE 5680 Mobile Communication Systems**

Spring. 4 credits. Prerequisites: ECE 4110 and 4670.

Theory and analysis of mobile communication systems, with an emphasis on understanding the unique characteristics of these systems. Topics include cellular planning, mobile radio propagation and path loss, characterization of multipath and fading channels, modulation and equalization techniques for mobile radio systems, source coding techniques, multiple access alternatives, CDMA system design, and capacity calculations.

**ECE 5720 Parallel Computer Architecture (also CS 5722)**

Fall. 4 credits. Prerequisite: ECE 4750.

Principles and trade-offs in the design of parallel architectures. Emphasis is on latency, bandwidth, and synchronization in parallel machines. Case studies illustrate the history and techniques of shared-memory, message-passing, dataflow, and data-parallel machines. Additional topics include memory consistency models, cache coherence protocols, and interconnection network topologies. Architectural studies presented through lecture and some research papers.

**[ECE 5740 Advanced Digital VLSI**

Fall. 4 credits. Prerequisites: ECE 3140 and ECE 4740. Next offered 2009–2010.

Top-down approach to asynchronous design and the relation between computer architecture and VLSI design. For the asynchronous design component: high-level synthesis, design by program transformations, and correctness by construction. Topics include delay-insensitive design techniques, description of circuits as concurrent programs, circuit compilation, and electrical optimizations. Students will complete a group project of the design of a microprocessor.]

**ECE 5750 Advanced Microprocessor Architecture**

Spring. 4 credits. Prerequisite: ECE 4750 or CS 4420.

This course is a revised version of the former ECE 575 High-Performance Microprocessor Architecture. In addition to performance enhancement techniques of modern single-core microprocessors such as branch prediction and speculation methods, which have been the focus of ECE 5750, this course will also discuss reconfigurable architecture, on-chip interconnect, and non-performance issues such as security and verification.

**ECE 5760 Advanced Microcontroller Design**

Fall. 4 credits. Prerequisites: ECE 4750 and ECE 4760 or equivalent.

Design of system-on-chip applications. Students working in pairs design, debug, and construct several systems that illustrate the design of embedded processors with custom peripherals running a real-time operating system. The content focuses on laboratory work. The lectures are used primarily for the introduction of examples, description of specific modules to be designed, and instruction in the hardware and high-level design tools to be employed.

**ECE 5780 Computer Analysis of Biomed Images**

Spring. 4 credits. Prerequisite: permission of instructor; engineering, biomedical, or biology background.

Powerful imaging modalities with attending computer image processing methods are evolving for the evaluation of health and the detection of disease. This course focuses on the quantitative analysis of such images and Computer Aided Diagnosis (CAD), i.e., the automatic identification and classification of abnormalities by the computer.

**ECE 5790 Advanced High-Speed and RF Integrated Circuits**

Spring, 4 credits. Prerequisites: ECE 4330 and ECE 4530.

Principles of analog integrated circuit design in the Giga-Hertz frequency range. This course covers the fundamental understanding of high-frequency circuit building blocks such as low noise amplifiers, mixers, oscillators, phase locked loops, frequency synthesizers, clock and data recoveries, and power amplifiers. Additionally, because some of the traditional microwave building blocks such as transmission lines and distributed circuit elements are essential parts of today's high speed integrated circuits, the course will briefly cover them. Throughout the course, a systematic review of advanced wireless and wireline applications would be covered. The course emphasizes physical understanding and intuitive design methods as well as qualitative techniques and computer simulations. The course has collaborative class projects, based on real-world problems.

**ECE 5810 Introduction to Plasma Physics**

Fall. 4 credits. Prerequisite: ECE 3030 or equivalent. First-year graduate-level course; open to exceptional seniors.

Topics include plasma state; motion of charged particles in fields; drift-orbit theory; coulomb scattering, collisions; ambipolar diffusion; elementary transport theory; two-fluid and hydromagnetic equations; plasma oscillations and waves, CMA diagram; hydromagnetic stability; and elementary applications to space physics, plasma technology, and controlled fusion.

**ECE 5820 Advanced Plasma Physics**

Fall. 4 credits. Prerequisite: ECE 5810.

Boltzmann and Vlasov equations; waves in hot magnetized plasma; Landau and cyclotron damping; micro-instabilities; low-frequency waves and instabilities; nonlinear phenomena: solitons, nonlinear waves, tearing, and reconnection.

**ECE 5830 Introduction to Technical Management**

Fall. 3 credits. Prerequisite: industrial experience or equivalent (summer work or school work).

This course is taught from the perspective of a chief technology officer and is targeted at M. Eng. and management students interested in "real world" problems. It provides an introduction via case examples to the technical, management, and organizational issues of developing and marketing products in high-tech businesses. The focus is on the unique nature of this type of business, including managing with high risk/uncertainty levels, learning to manage very diverse project teams, and recognizing technical versus market success in order to make good business decisions.

**ECE 5840 Advanced GPS Receiver Design**

Spring. 4 credits. Prerequisite: ECE 4150 or MAE 4150.

GPS receiver design from the RF section to the observables is investigated and implemented in MATLAB software. Creation of C/A code, upsampling, down conversion, code correlation, acquisition, tracking, and interpreting the navigation message. Students start with the digitized GPS bandwidth and build a software receiver to create the navigation solution as the final project.

**ECE 5870 Energy Seminar I (also CHEME 5870, MAE 5450)**

Fall. 1 credit.

Energy resources, their conversion to electricity or mechanical work, and the environmental consequences of the energy cycle are discussed by faculty members from several departments in the university and by outside experts. Topics include: energy resources and economics; coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; and air pollution control.

**ECE 5880 Energy Seminar II (also CHEME 5880, MAE 5460)**
Spring. 1 credit.
For description, see ECE 5870; however, different speakers and/or topics are discussed in ECE 5880.

**ECE 5930–5990 Advanced Topics in Electrical and Computer Engineering**
Fall, spring. 1–4 credits.
Seminar, special interest, or temporary course.

**[ECE 6100 Graduate Seminar in Medical Instrumentation**
Fall. 1 credit. S–U grades only. Offered alternate years; next offered 2009–2010.
The seminar will provide a format for identifying, investigating, and discussing state-of-the-art developments related to instrumentation, analysis techniques, and simulation sciences as they apply to biomedical problems and solutions.]

**[ECE 6680 Foundations of Probability and Probabilistic Reasoning**
Spring. 3 credits. Prerequisites: a course in standard probability such as ECE 3100, ECE 4110, or ORIE 6510 and some exposure to statistical reasoning, such as ECE 5640. Offered alternate years. Next offered 2009–2010.
An examination of issues in the interpretations and axiomatizations of probability and of the connections between probability and probabilistic reasoning. Emphasis will be placed upon such alternative mathematical models of probability as are provided by modal, order relations, interval-valued, and sets of measures. These models will be related to interpretations of probability that include the familiar frequency of occurrence, computational complexity, classical, subjective, epistemic, and propensity. This course requires only a familiarity with standard numerical probability and some of its applications. However, mathematical maturity, in the sense of comfort when faced with new mathematical ideas that will be fully defined, will be valuable in dealing with new probability concepts.]

**ECE 6830 Seminar in GPS and GNSS**
Fall, spring. 1–3 credits. Prerequisite: ECE/MAE 4150 or equivalent.
Seminar in GPS (Global Positioning System) and GNSS (Global Navigation Satellite Systems) science and engineering. Current topics in receiver design such as low signal acquisition, ambiguity resolution, and software receivers and topics in GPS science such as space weather effects on GPS and the use of GPS for remote sensing. Students typically make one presentation during the semester.

**ECE 6930 Master of Engineering Design**
Fall and spring. 3–8 credits. Two-semester course: must enroll both semesters; will receive R grade for first semester. For students enrolled in M.Eng. (Electrical and Computer Engineering) degree program.
Uses real engineering situations to present fundamentals of engineering design. Each professor is assigned a section number. To register, see roster for appropriate six-digit course ID numbers.

**ECE 6970–6980 Master of Engineering Research**
6970, fall; 6980, spring. 7 credits. Prerequisite: For students enrolled in M.Eng. (Electrical) degree Research Track program. Must enroll both semesters.
Project designed for the M.Eng. student in the Research Track program and more resembles a research thesis. Students will work closely with an ECE Graduate Field Faculty member on a common area of interest. Each professor is assigned a section number. To register, see roster for appropriate six-digit course ID numbers.

**ECE 7910–7920 Thesis Research**
7910, fall; 7920, spring. 1–15 credits. For students enrolled in master's or doctoral program. Each professor is assigned a section number. To register, see roster for appropriate six-digit course ID numbers.

## INFORMATION SCIENCE, SYSTEMS, AND TECHNOLOGY

C. Cardie, director; W. Arms, G. Bailey, K. Bala, R. Caruana, E. Friedman, J. Gehrke, C. Gomes, J. Halpern, D. Huttenlocher, P. Jackson, T. Joachims, J. Kleinberg, L. Lee, D. Ruppert, P. Rusmevichientong, B. Selman, D. Shmoys, E. Tardos, D. Williamson

For complete descriptions, see the INFO listing in the CIS section.

**INFO 1301 Introduction to Programming Web Applications**
Fall, weeks 1–7. 2 credits. Students must enroll in both INFO 1301 and 1302.
For description, see INFO 1301 in CIS section.

**INFO 1302 Introduction to Designing Web Applications**
Fall, weeks 8–14. 2 credits. Students must enroll in both INFO 1301 and 1302. Prerequisite: successful completion of INFO 1301.
For description, see INFO 1302 in CIS section.

**INFO 2040 Networks (also ECON 2040, SOC 2120) (SBA)**
Spring. 4 credits.
For description, see ECON 2040.

**INFO 2140 Cognitive Psychology (also COGST/PSYCH 2140) (KCM)**
Fall. 4 credits. Limited to 175 students. Prerequisite: sophomore standing. Graduate students, see INFO 6140.
For description, see PSYCH 2140.

**INFO 2300 Intermediate Design and Programming for the Web (also CS 2300)**
Spring. 3 credits. Prerequisite: INFO 1301 and 1302 strongly recommended.
For description, see INFO 2300 in CIS section.

**INFO 2310 Topics in Web Programming and Design**
Fall, weeks 1–10. 1 credit. Prerequisite: INFO 2300.
For description, see INFO 2310 in CIS section.

**INFO 2450 Psychology of Social Computing (also COMM 2450) (SBA)**
Fall, summer. 3 credits.
For description, see COMM 2450.

**INFO 2921 Inventing an Information Society (also AMST/ECE/ENGRG 2980, HIST 2920, STS 2921)**
Spring. 3 credits.
For description, see ENGRG 2980.

**INFO 2950 Mathematical Methods for Information Science**
Fall. 4 credits. Corequisite: MATH 2310 or equivalent.
For description, see INFO 2950 in CIS section.

**INFO 3200 New Media and Society (also COMM 3200)**
Spring. 3 credits.
For description, see COMM 3200.

**INFO 3300 Data-Driven Web Applications (also CS 3300)**
Spring. 3 credits. Prerequisite: CS 2110.
For description, see INFO 3300 in CIS section.

**INFO 3450 Human–Computer Interaction Design (also COMM 3450) (SBA)**
Spring. 3 credits.
For description, see COMM 3450.

**INFO 3490 Media Technologies (also COMM 3490, STS 3491) (CA)**
Spring. 3 credits. Offered odd-numbered years.
For description, see COMM 3491.

**INFO 3551 Computers: From the 17th Century to the Dotcom Boom (also STS 3551) (HA)**
Fall. 4 credits.
For description, see STS 3551.

**[INFO 3561 Computing Cultures (also STS 3561)**
Spring. 4 credits. No technical knowledge of computer use presumed or required. INFO 355 and 356 may be taken separately or in any order. Next offered 2009–2010.
For description, see STS 3561.]

**INFO 3650 Technology in Collaboration (also COMM 3650)**
Spring. 3 credits. Prerequisite: COMM/INFO 2450.
For description, see COMM 3650.

**[INFO 3660 History and Theory of Digital Art (also ARTH 3650) (CA)**
Fall. 4 credits. Next offered 2009–2010.
For description, see ARTH 3650.]

**[INFO 3720 Explorations in Artificial Intelligence (also CS 3700)**
Spring. 3 credits. Prerequisites: MATH 1110 or equivalent, an information science approved statistics course, and CS 2110 or permission of instructor. Next offered 2009–2010.
For description, see INFO 3720 in CIS section.]

**[INFO 3871 The Automatic Lifestyle: Consumer Culture and Technology (also STS 3871) (CA)]**

**[INFO 4290 Copyright in the Digital Age (also COMM 4290)**
Fall. 3 credits. Offered odd-numbered years.
For description, see COMM 4290.]

**INFO 4300 Information Retrieval (also CS 4300)**
Fall. 3 credits. Prerequisite: CS/ENGRD 2110 or equivalent.
For description, see INFO 4300 in CIS section.

**INFO 4302 Web Information Systems (also CS 4302)**
Spring. 3 credits. Prerequisites: CS 2110 and some familiarity with web site technology.
For description, see INFO 4302 in CIS section.

**INFO 4350 Seminar on Applications of Information Science (also INFO 6390)**
Spring. 3 credits. Prerequisites: background in computing, data structures, and programming at level of CS 2110 or equivalent; experience using information systems. Undergraduate and master's students should register for INFO 4350; Ph.D. students should register for INFO 6350.
For description, see INFO 4350 in CIS section.

**INFO 4400 Advanced Human-Computer Interaction Design (also COMM 4400) (SBA)**
Fall. 3 credits. Prerequisite: INFO 2450.
For description, see COMM 4400.

**[INFO 4144 Responsive Environments (also ARTH 4144) (CA)**
Spring. 4 credits. Next offered 2009–2010.
For description, see ARTH 4144.]

**[INFO 4450 Seminar in Computer-Mediated Communication (also COMM 4450)**
Fall. 3 credits. Prerequisite: INFO 2450. Next offered 2009–2010.
For description, see COMM 4450.]

**INFO 4470 Social and Economic Data (also ILRLE 4470)**
Spring. 4 credits. Prerequisites: one semester of calculus, IS statistics requirement, one upper-level social science course, or permission of instructor.
For description, see INFO 4470 in CIS section.

**[INFO 4500 Language and Technology (also COMM 4500) (SBA)**
Spring. 3 credits. Prerequisite: INFO 2450 or permission of instructor. Next offered 2009–2010.
For description, see COMM 4500.]

**[INFO 4850 Computational Methods for Complex Networks**
Spring. 3 credits. Prerequisites (2): ECON/ INFO 2040/SOC 2090/CS 2850 or equivalent knowledge; CS 2110 or INFO 2300 or equivalent knowledge of basic programming.
For description, see INFO 4850 in CIS section.]

**INFO 4900 Independent Reading and Research**
Fall, spring. 1–4 credits.

**INFO 4910 Teaching in Information Science, Systems, and Technology**
Fall, spring. Variable credit.

**INFO 5150 Culture, Law, and Politics of the Internet**
Fall. 4 credits.
For description, see INFO 5150 in CIS section.

**INFO 5300 The Architecture of Large-Scale Information Systems (also CS 5300)**
Spring. 4 credits. Prerequisite: INFO 3300 or CS 4320.
For description, see INFO 5300 in CIS section.

**[INFO 6002 Critical Technical Practices]**

**INFO 6140 Cognitive Psychology (also COGST/PSYCH 6140)**
Fall. 4 credits.
For description, see PSYCH 6140.

**[INFO 6144 Responsive Environments (also ARTH 6144)**
Spring. 4 credits. Next offered 2009–2010.
For description, see ARTH 6144.]

**INFO 6300 Advanced Language Technologies (also CS 6740)**
Fall or spring, next offered fall 2008. 3 credits. Prerequisite: permission of instructor. Neither INFO/CS 4300 nor CS 4740 are prerequisites.
For description, see CS 6740 in CIS section.

**INFO 6350 Seminar on Applications of Information Science (also INFO 4350)**
Spring. 3 credits. Prerequisites: background in computing, data structures, and programming at level of CS 2110 or equivalent; experience in using information systems. Undergraduates and master's students should register for INFO 4350; Ph.D. students should register for INFO 6350.
For description, see INFO 6350 in CIS section.

**INFO 6400 Human–Computer Interaction Design (also COMM 6400)**
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.
For description, see COMM 6400.

**[INFO 6450 Seminar in Computer-Mediated Communication (also COMM 6450)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Next offered 2009–2010.
For description, see COMM 6450.]

**INFO 6648 Speech Synthesis by Rule (also LING 6648)**
Spring. 4 credits. Prerequisite: LING 4401, 4419, or permission of instructor.
For description, see LING 6648.

**[INFO 6500 Language and Technology (also COMM 6500)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Next offered 2009–2010.
For description, see COMM 6500.]

**INFO 6850 The Structure of Information Networks (also CS 6850)**
Fall. 4 credits. Prerequisite: CS 4820.
For description, see INFO 6850 in CIS section.

**INFO 7090 IS Colloquium**
Fall, spring. 1 credit. For staff, visitors, and graduate students interested in information science.

**INFO 7470 Social and Economic Data (GR-RDC) (also ILRLE 7400)**
Spring. 4 credits. Prerequisite: Ph.D. and research master's students.
For description, see INFO 7470 in CIS section.

**INFO 7900 Independent Research**
Fall, spring. Variable credit. Prerequisite: permission of an information science faculty member.
Independent research for M.Eng. students and pre–A exam Ph.D. students.

**INFO 9900 Thesis Research**
Fall, spring. Variable credit. Prerequisite: permission of an information science faculty member.
Thesis research for post–A exam Ph.D. students.

# MATERIALS SCIENCE AND ENGINEERING

E. P. Giannelis, director; D. G. Ast, S. P. Baker, J. M. Blakely, R. Dieckmann, L. Estroff, D. T. Grubb, R. Hennig, C. Liddell, G. G. Malliaras, C. K. Ober, D. G. Schlom, M. O. Thompson, C. C. Umbach, R. B. van Dover, U. B. Wiesner

## Undergraduate Courses

**MSE 1110 Nanotechnology (also ENGRI 1110)**
Fall. 3 credits. E. Giannelis.
Course in Introduction to Engineering series. For description, see ENGRI 1110.

**MSE 1180 Design Integration: DVDs and iPods (also ENGRI/TAM 1180)**
Spring. 3 credits. Course in Introduction to Engineering series.
For description see ENGRI 1180.

**MSE 1190 Biomaterials for the Skeletal Systems (also ENGRI 1190)**
Fall. 3 credits. D. Grubb.
Course in Introduction to Engineering series. For description, see ENGRI 1190.

**MSE 1810 MSE At Cornell: an Introduction for Freshman**
Spring. 1 credit. S–U or letter grade; grade based on class participation and a course project. C. Umbach.
Introduces materials science and engineering to students considering MSE as their major. Lectures by MSE professors, alumni, and industrial researchers. Topics covered: MSE major requirements as preparation for real-world engineering. Cutting-edge MSE research involving undergraduates. Industrial R&D. Tours of Cornell centers and MSE facilities.

**MS&E 1910–1920 Research Involvement Ia and Ib**
Fall, 1910; spring, 1920. 3 credits each semester. Prerequisite: approval of department. Staff.
For description, see MSE 2910. May be continuation or a one-semester affiliation with a research group.

**MSE 2060 Atomic and Molecular Structure of Matter (also MAE 3130)**
Spring. 4 credits. C. Liddell.
Discusses the basic elements of structure; order and disorder; ideal gas; crystals; liquids; amorphous materials; polymers; liquid crystals; composites; crystal structure; x-ray diffraction.

**MSE 2610 Mechanical Properties of Materials: From Nanodevices to Superstructures (also ENGRD 2610)**
Fall. 3 credits. Prerequisite: MATH 1910. Corequisite: PHYS 1112 or permission of instructor. S. P. Baker.
For description, see ENGRD 2610.

**MSE 2620 Electronic Materials for the Information Age (also ENGRD 2620)**
Spring. 3 credits. Prerequisite: MATH 1920. Corequisite: PHYS 2213 or permission of instructor. G. Malliaras.
For description, see ENGRD 2620.

**MSE 2910–2920 Research Involvement IIa and IIb**
2910, fall; 2920, spring. 3 credits each semester. Prerequisite: approval of department. Staff.

Supervised independent research project in association with faculty members and faculty research groups of the department. Students design experiments, set up the necessary equipment, and evaluate the results. Creativity and synthesis are emphasized. Each semester may be taken as a continuation of a previous project or as a one-semester affiliation with a research group.

**MSE 3010 Materials Chemistry (also MSE 5810)**

Fall. 3 credits. L. Estroff.

Provides a molecular understanding of materials properties: quantum chemistry, symmetry aspects of chemical bonding, solid state reactions, and electrochemistry. Materials include polymers, organic semiconductors, organic-inorganic hybrids, and biomaterials.

**MSE 3030 Thermodynamics of Condensed Systems (also MSE 5830)**

Fall. 4 credits. Prerequisites: PHYS 2214 and MATH 2940. M. O. Thompson.

Introduces the three laws of thermodynamics as the fundamental basis for thermal and chemical equilibrium, coupled with statistical mechanical interpretations for entropy and specific heat capacities. Applies these principles to understanding phase equilibria and phase diagrams, heterogeneous reactions, solutions, surfaces, and defects. Introduces electrochemistry and fuel/power cells.

**MSE 3040 Kinetics, Diffusion, and Phase Transformations (also MSE 5840)**

Spring. 4 credits. Prerequisite: MSE 3030 or permission of instructor. R. Hennig.

Topics include phenomenological and atomistic theories of diffusion; diffusion in metals, alloys, and nonmetals, including polymers; diffusion in the presence of driving forces; fast diffusion paths; thermo- and electrotransport; interfaces and microstructure; nucleation and growth; growth of product layers (parabolic and linear kinetics); solidification of alloys; diffusional and diffusionless transformations in solids; glass transition.

**MSE 3050 Electronic, Magnetic, and Dielectric Properties of Materials (also MSE 5850)**

Spring. 3 credits. Prerequisite: MSE 2060 and MSE 2620 or permission of instructor. R. B. van Dover.

Electronic structure of materials and connection to transport, magnetic, and dielectric properties. Wave and particle nature of electrons, wave packets, potential wells, barriers, tunneling. Valence electron behavior in crystals, density of states for metals, Fermi level, field and thermionic emission, Schottky barriers. Periodic potentials and band structure of crystals. Intrinsic and doped semiconductors, junction electronic and optical devices. Physical origin of magnetic behavior, ferromagnetic domains, magneto-resistance. Materials for data storage and manipulation. Polarization in dielectric materials; frequency dependence of dielectric constants and refractive indices. Ferroelectric domains. Dielectric components in devices. The close connection between fundamental concepts and current technology is emphasized.

**MSE 3070 Materials Design Concepts I**

Fall. 2 credits. C. Umbach.

For description, see MSE 4070.

**MSE 3110 Junior Laboratory I**

Fall. 1 credit. D. Ast.

Practical laboratory covering the analysis and characterization of materials and processing. Labs are based on materials from courses in chemistry of materials and thermodynamics of condensed systems.

**MSE 3120 Junior Laboratory II**

Spring. 1 credit. D. Ast.

Practical laboratory covering the analysis and characterization of materials and processing. Labs are based on course material in kinetics, diffusion, and phase transformation and electronic, magnetic, and dielectric properties of materials.

**MSE 3910–3920 Research Involvement IIIa and IIIb**

3910, fall; 3920, spring. 3 credits each semester. Prerequisite: departmental approval. Staff.

For description, see MSE 2910. May be continuation or a one-semester affiliation with a research group.

**MSE 4020 Mechanical Properties of Materials, Processing, and Design (also MAE 3120, MSE 5820)**

Fall. 3 credits. Prerequisite: MSE 2060. Corequisite: MSE 3040 or permission of instructor. D. Ast.

Relationship between microscopic mechanisms and macroscopic mechanical behavior of engineering materials, how mechanical properties can be modified, and criteria for selection and use of materials in design. Stress, strain and elastic constants as tensor quantities, viscoelasticity and damping, plastic deformation, creep deformation, fracture, and fatigue.

**MSE 4030–4040 Senior Materials Laboratory I and II**

4030, fall; 4040, spring. 3 credits each semester. Staff.

Practical laboratory covering the analysis and characterization of materials and processing. Emphasis is on design of experiments for evaluation of materials' properties and performance as related to processing history and microstructure. Projects available in areas such as plasticity, mechanical and chemical processing, phase transformations, electrical properties, magnetic properties, and electron microscopy.

**MSE 4050–4060 Senior Thesis I and II**

4050, fall; 4060, spring. 4 credits each semester. Requirement for graduation with honors. Open to advanced undergraduates in lieu of senior materials laboratory. M. Thompson.

Proposals for thesis topics should be approved by the supervising faculty member before beginning the senior year. Approved thesis topics normally involve original experimental research in direct collaboration with an ongoing research program. Periodic oral and written presentations and a final written thesis are required. Students must take both semesters to complete the laboratory requirement.

**MSE 4070 Materials Design Concepts II**

Fall. 2 credits. C. Umbach.

Introduces materials design in the context of real world materials design projects carried out in industry. In the first portion of the course, the process of engineering design is studied in light of economic, environmental, regulatory, and safety issues. Patent searching and communication skills are addressed. In the second portion, speakers from industry lecture on case studies of materials design problems. Students give oral presentations and write technical reports based on case studies.

**[MSE 4100 Physical Metallurgy and Applications (also MSE 6100)**

Spring. 3 credits. Prerequisites: MSE 2060, 3030, 3040 or permission of instructor. S. Baker. Next offered 2009–2010.

Microstructure and properties of metals and alloys: processing, structure, defects, phase stability, diffusion, deformation, fracture, corrosion, conductivity, optical properties. Applications of metallurgical principles to high performance metallic materials include: thin films and patterned structures for use in microelectromechanical systems, superalloys for high temperature engine applications, shape memory alloys for biomedical applications, and others.]

**[MSE 4330 Materials for Energy Production, Storage, and Conversion (also MSE 5330)**

Fall. 3 credits. Next offered 2009–2010. R. Dieckmann.

Concerned with materials and technologies related to energy production, storage, and conversion as well as to sensors used for monitoring the emission of pollutants. The devices discussed include solar cells, fuel cells, batteries, and electrochemical sensors. Thermodynamic, kinetic, and electrochemical concepts and materials properties critical for such devices are the central part of this course.]

**MSE 4610 Biomedical Materials and Their Applications**

Spring. 3 credits. D. Grubb.

Many types of materials are used in biomedical engineering to replace or supplement natural biological systems. Interaction with blood and tissues is always of primary importance, but depending on the use of the biomedical material, mechanical, optical, and transport properties may also be vital. After a general introduction to biomedical materials, case studies involving physiological systems are considered, and design of artificial parts and materials are investigated. Constraints such as methods of production, economics, regulatory approval, and legal liabilities are included. Examples may include dialysis, contact and intra-ocular lenses, heart valves, and the artificial pancreas. Every student is involved in a presentation about a case study.

**MSE 4810 Technology Management (also MSE 5870)**

Spring. 3 credits. E. P. Giannelis.

Designed to provide students in engineering and the sciences with the knowledge and analytical skills to manage RD for a strategic competitive advantage. Most organizations recognize the critical importance of RD management in becoming and remaining world-class competitors. The course uses a combination of case studies, readings, discussions, and outside lectures. Topics include technology evaluation, RD portfolio, intellectual property portfolio and management, technology transfer, and technology, policy, and society.

**MSE 4820 Plasma Processing of Electronic Materials (also ECE 4820)**
Spring. 3 credits. Prerequisites: PHYS 2213 and 2214 or equivalents. Offered if sufficient demand.
For description, see ECE 4820.

**MSE 4870 Ethics and Technology**
Spring. 1 credit. Staff.
Ethics influences all decisions made by a technologist. This course discusses those factors that must be considered in reaching a decision involving technology, ranging from legal impact to consideration of community expectations.

**MSE 4890 Colloids and Colloid Assemblies for Advanced Materials Applications (also MSE 5890)**
Fall. 3 credits. C. Liddell.
Recent global developments in the synthesis, modification, organization, and utilization of fine particles in nanotechnology and biotechnology fields. Underlying principles for control of particle characteristics such as mean size, shape, composition, internal homogeneous structure, layered, hollow, porous, and heterojunction structures. Methods for the formation of ordered and patterned particle arrays employed in advanced materials based on latex, ceramic colloids, metal nanoparticles, semiconductor quantum dots, nanocapsules, and miniemulsions. Applications in photonics, biolabeling, biological screening, drug delivery, catalysis, and magnetic recording.

**MSE 4910–4920 Research Involvement IVa and IVb**
4910, fall; 4920, spring. 3 credits each semester. Prerequisite: departmental approval. Staff.
For description, see MSE 2910. May be continuation or a one-semester affiliation with a research group.

**MSE 4950 Undergraduate Teaching Involvement**
Fall, spring. Variable credit. Staff.
Gives credit to students who help in the laboratory portions of select MSE courses. The number of credits earned is determined by the teaching load and is typically 1–3.

**MSE 5010–5020 Special Project**
Fall, spring. 6 credits. Staff.
Master of Engineering research project.

**[MSE 5120 Mechanical Properties of Thin Films (also MAE 5130)**
Spring. 3 credits. Prerequisite: A course similar to ENGRD 2610 or permission of instructor. S. P. Baker. Next offered 2009–2010.
Stresses, elastic and plastic deformation, creep and anelasticity, and fracture and delamination of thin films and patterned structures. How mechanical behavior at the nanoscale deviates from the predictions of scaling laws derived for bulk materials. Applications in microelectronics, optics, microelectromechanical systems, coatings, etc.]

**MSE 5210 Properties of Solid Polymers**
Fall. 3 credits. Prerequisite: ENGRD 2610. Corequisite: MSE 3030 or permission of instructor. C. Ober.
Synthetic and natural polymers for engineering applications. Production and characterization of long-chain molecules. Thermodynamics of polymer mixtures. Polymer molecular weight. Gelation and networks, rubber elasticity, elastomers, and thermosetting resins. Amorphous and crystalline thermoplastics and their structure. Time- and temperature-dependent elastic properties of polymers. Glass transition and secondary relaxations. Plastic deformation and molecular orientation.

**[MSE 5230 Physics of Soft Materials**
Fall. 3 credits. Next offered 2009–2010. U. Wiesner.
The course covers general aspects of structure, order, and dynamics of soft materials. Typical representatives of this class of materials are polymers, liquid crystals, gels, and surfactant solutions. A general formalism for the description of order in terms of orientation distribution functions is introduced. Examples are given for the measurement of order parameters for partially ordered materials. Finally, the dynamics of soft materials is discussed. Besides transport and flow behavior aspects of the local dynamics of soft materials are presented. Emphasis is put on the discussion of various techniques frequently used (and available at Cornell) for the characterization of structure, order and dynamics of soft materials such as NMR or various scattering techniques. Using examples of modern multidimensional spectroscopic methods the issue of heterogeneous dynamics at the glass transition of amorphous liquids is presented at the end of the class.]

**[MSE 5250 Organic Optoelectronics**
Fall. 3 credits. G. G. Malliaras. Next offered 2009–2010.
The course begins with an overview of relevant materials, from small aromatic molecules to conjugated polymers. We then discuss their optoelectronic properties, including topics from photophysics (absorption, emission, photogeneration, recombination), charge transport and injection (doping, hopping, disorder) and nonlinear optics. Molecular conduction mechanisms are reviewed. Their applications in electrophotography, light-emitting diodes, lasers, photovoltaic cells, thin film transistors are then discussed.]

**MSE 5310 Introduction to Ceramics**
Spring. 3 credits. Prerequisites: all MSE 2000- and 3000-level core courses. R. Dieckmann.
Covers ceramic processes and products, structure of ceramic crystals, structure of glasses, structural defects (point defects, dislocations), surfaces, interfaces and grain boundaries, diffusion in ionic materials (atomistic and phenomenological approach, relationships between diffusion and point defect structure), ceramic phase diagrams, phase transformations. Emphasizes physicochemical aspects of the different topics.

**[MSE 5330 Materials for Energy Production, Storage, and Conversion (also MSE 5330)**
Fall. 3 credits. Next offered 2009–2010. R. Dieckmann.
For description, see MSE 4330.]

**MSE 5410 Nanofabrication of Semiconductor Devices (also ECE 5360)**
Fall. 4 credits. Prerequisites: ECE 3150 and ECE 4570 or equivalent.
For description, see ECE 5360.

**[MSE 5420 Flexible Electronics**
Spring. 3 credits. C. Ober. Next offered 2009–2010.
Flexible electronics holds the promise of transformative developments in: (1) flat panel lighting (low cost, low energy), (2) energy production systems (solar), and (3) infrastructure control and monitoring (sensing, energy control, hazard monitoring). Practical realization of flexible circuits will require dramatic progress in new materials that are compatible with flexible media and amenable to facile and low temperature processing as well as major advances in manufacturing technologies such as roll-to-roll processing. This course will discuss these and other developments.]

**[MSE 5430 Thin-Film Materials Science**
Fall. 3 credits. R. B. van Dover. Next offered 2009–2010.
Provides fundamental information on the deposition, properties, reaction, and evaluation of thin films. Topics include deposition techniques, surface energies, stress in thin films, surface kinetics, homoepitaxy, heteroepitaxy and superlattices, electrical and optical properties, Schottky barriers, solid phase regrowth, interdiffusion, thin film reactions, and electromigration. The recommended textbook is *Electronic Thin Film Science for Electrical Engineers and Material Scientists* by Tu, Mayer, and Feldman.]

**MSE 5450 Magnetic and Ferroelectric Materials**
Fall. 3 credits. Prerequisites: PHYS 2213 and 2214 or equivalent. R. B. van Dover.
Topics include magnetic fields, the microscopic origins of magnetism, ferromagnetic materials and properties and applications of magnetic materials. The properties of ferroelectric materials are also covered, and applications of ferroelectrics in electronics technology are explored.

**MSE 5490 Nanofabrication: Making It Small**
Spring. 3 credits. Prerequisites: CHEM 2090, MATH 1920. M. Thompson
This course provides an introduction to principles and parctice of nanofabrication techniques, combining lectures with hands-on laboratory fabrication. A range of nanosystems will be explored from microelectronic circuits to MEMS sensors and/or microfluidics. Fundamentals common to all fabrication including lithography, deposition, and etching processes are explored in lectures and lab exercises. New developments in “soft” microstamp lithography and self-assembly methods are discussed. In the final project students build one of several nanosystems depending on their particular interests.

**MSE 5550 Introduction to Composite Materials (also CEE/MAE/TAM 4550)**
Fall. 3 credits. P. Petrina.
For description, see TAM 4550.

**MSE 5620 Biomineralization: The Formation and Properties of Inorganic Biomaterials**
Spring 3 credits. Prerequisites: MSE 3010 or CHEM 1570 or CHEM 3570–3580 or equivalent or permission of instructor. L. Estroff.
This course will examine the wide variety of mineralized materials made by biological organisms including mollusk shells, mammalian bone and teeth, silica bodies in plants, and magnetotactic bacteria. The focus will be on the molecular and biological mechanisms that lead to the formation of these materials as

well as their unique materials properties (mechanical, optical, magnetic).

**MSE 5630 Nanobiotechnology (also AEP/ BIOG 6630)**
Fall. 3 credits.
For description, see BME 6670.

**[MSE 5710 Analytical Techniques for Material Science**
Spring. 3 credits. D. Grubb. Next offered 2009–2010.
Survey of modern analytical techniques used to determine composition and structure of near-surface and bulk materials. Interaction of ions, electrons, and photons with solids; characteristics of the emergent radiation. Techniques covered include ion scattering, Auger electron spectroscopy, nuclear activation, secondary ion mass spectroscopy, UV and X-ray photoelectron spectroscopies, and X-ray techniques. Selection and design of experiments.]

**[MSE 5720 Computational Materials Science**
Fall. 3 credits. Prerequisite: MSE 3030/6010 or equivalent. R. Hennig. Next offered 2009–2010.
Computational methods for predicting the behavior of condensed matter systems, including Monte Carlo, molecular dynamics, and phase field approaches. Extraction of physical parameters from simulation results and limitations of computational methods. Survey of interatomic potential development and quantum-mechanical ab-initio techniques. Examples drawn from surface and condensed phase systems.]

**MSE 5810 Materials Chemistry (also MSE 3010, MAE 3120)**
Spring. 3 credits. L. Estroff.
For description, see MSE 3010.

**MSE 5820 Mechanical Properties of Materials, Processing, and Design (also MSE 4020, MAE 3120)**
Fall. 3 credits. Corequisite: MSE 5840 or permission of instructor. S. Ast.
For description, see MSE 4020.

**MSE 5830 Thermodynamics of Condensed Systems (also MSE 3030)**
Fall. 4 credits. M. O. Thompson.
For description, see MSE 3030.

**MSE 5840 Kinetics, Diffusion, and Phase Transformation (also MSE 3040)**
Spring. 4 credits. Prerequisite: MSE 5830 or permission of instructor. R. Hennig.
For description, see MSE 3040.

**MSE 5850 Electronic, Magnetic, and Dielectric Properties of Materials (also MSE 3050)**
Spring. 3 credits. R. B. van Dover.
For description, see MSE 3050.

**MSE 5870 Technology Management (also MSE 4810)**
Spring. 3 credits. E. P. Giannelis.
For description, see MSE 4810.

**MSE 5890 Colloids and Colloid Assemblies for Advanced Materials Applications (also MSE 4890)**
Fall. 3 credits. C. Liddell.
For description, see MSE 4890.

## Graduate Core Courses

**MSE 6010 Chemistry of Materials**
Spring. 3 credits. Prerequisite: thermodynamics course at level of MSE 3030. U. Wiesner.
In this course modern developments in materials chemistry are taught and discussed. This includes symmetry aspects of chemical bonding, self-assembly, sol–gel chemistry, mesostructured and mesoporous solids, low-dimensional nanomaterials and bioorganic chemistry.

**MSE 6020 Elasticity, Plasticity, and Fracture**
Spring. 3 credits.
An advanced overview of mechanical properties of materials combining concepts from continuum mechanics, atomic structure, thermodynamics, and kinetics. Topics include: elastic properties of crystals, glasses, and polymers; mechanical damping; plastic deformation in metals and polymers; creep deformation; fracture in brittle and ductile materials; the effects of temperature, time, and thermomechanical history on properties; metals, ceramics, polymers, and composites; and models and scaling laws for mechanical behavior.

**[MSE 6030 Thermodynamics of Materials**
Spring. 3 credits. J. Blakely. Next offered 2009–2010.]

**MSE 6040 Kinetics of Reactions in Condensed Matter**
Spring. 3 credits. R. Dieckmann.
Phenomenology and microscopic aspects of diffusion in fluids, both simple and polymeric, and in metallic, ionic, semiconductor, and polymeric solids. Cartesian tensors are utilized for fields and properties. Covers phase stability and transformations; nucleation and growth, spinodal decomposition and displacive transformations; phase coursening processes, recrystallization, and grain growth; diffusion-controlled growth, interfacial reactions, moving boundary problems; grain-boundary migration controlled kinetics; viscosity, anelasticity, and diffusional creep.

**MSE 6050 Electronic Properties of Materials**
Spring. 3 credits. D. Schlom.
Develops concepts of band structure in crystalline and non-crystalline materials from a real-space as well as reciprocal space perspective, and reconciles the two approaches. Mathematical complexity is kept to a minimum. Specific topics include electronic properties of low-dimensionality materials (surfaces, quantum wires, quantum dots), optical properties of metals and insulators, and electronic properties of exotic materials such as oxide and organic semiconductors. Technological applications to be addressed include switching devices, magnetism, superconductivity, and photonics, depending on student interests.

**[MSE 6060 Condensed Matter Structure**
Fall. 3 credits. Prerequisite: course at level of MSE 2060. Next offered 2008–2009. J. Blakely.
Focuses on ways to characterize structure. Includes lectures by several faculty on structural determination on a wide range of materials. Elements of structure at length scales ranging from sub-nanometer to millimeter. Descriptions of structure in crystals, liquids, amorphous solids/glasses. Short- and long-range order, microstructures, cellular structures, domains, domain boundaries, 2-phase and composite structures. Techniques to probe structure: "direct" microscopy, real space imaging, including probe microscopies, optical, electron and X-ray methods. Indirect methods based on analysis of diffraction fields, Fourier/reciprocal space. Examples of application may include polymer structure, metal grain textures, dislocation arrays, cellular structure, structure of biological membranes, nano-composite structures, surfaces, interfaces and grain boundaries in semiconductors, structure of photonic materials, domain structures in ferroelectrics and ferromagnetics, biological materials.]

## Related Course in Another Department

Introductory Solid-State Physics (PHYS 4454, AEP 4500)

## Further Graduate Courses

**[MSE 6100 Physical Metallurgy and Applications (also MSE 4100)**
Spring. 3 credits. Prerequisites: MSE 2060, 3030, 3040 or permission of instructor. S. Baker. Next offered 2009–2010.
For description, see MSE 4100.]

**MSE 6210 Advanced Inorganic Chemistry III: Solid-State Chemistry (also CHEM 6070)**
Spring. 4 credits. Prerequisite: CHEM 6050 or permission of instructor. S. Lee.
For description, see CHEM 6070.

**MSE 6550 Composite Materials (also MAE/TAM 6550)**
Spring. 4 credits. Staff.
For description, see TAM 6550.

**MSE 6650 Principles of Tissue Engineering (also MAE/BME 6650)**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor.
For description, see BME 6650.

**MSE 6710 Principles of Diffraction (also AEP 7110)**
Spring. 3 credits. Letter grades only. Assumes some knowledge of statistical thermodynamics, crystallography, elementary quantum mechanics, and theory of rate processes. J. D. Brock.
For description, see AEP 7110.

**[MSE 6810 Surfaces and Interfaces in Materials**
Spring. 3 credits. J. Blakely. Next offered 2009–2010.
Deals with special topics in surface and interface science. The main topics are: statistical thermodynamics of interfaces, morphological stability, atomic structure, energetics and structure determination, electronic structure of interfaces, charge and potential distributions, surface steps, adsorption and segregation, atomic transport and growth processes at surfaces, oxidation, and other surface reactions.]

## Specialty Courses

**MSE 8000 Research in Materials Science**
Fall, spring. Credit TBA. Staff.
Independent research in materials science under the guidance of a member of the staff.

**MSE 8010 Materials Science and Engineering Colloquium**
Fall and spring. 1 credit each semester. Enrollment limited to MSE Ph.D. students. Staff.

Lectures by visiting scientists, Cornell staff members, and graduate students on subjects of interest in materials sciences, especially in connection with new research.

**MSE 8020 Materials Science Research Seminars**

Fall, spring. 2 credits each semester. Prerequisite: graduate students involved in research projects. Staff.

Short presentations on research in progress by students and staff.

## MECHANICAL AND AEROSPACE ENGINEERING

P. L. Auer, C. T. Avedisian, D. L. Bartel, L. J. Bonassar, J. F. Booker, J. R. Callister, M. E. Campbell, D. A. Caughey, L. R. Collins, P. R. Dawson, P. C. T. deBoer, D. C. Erickson, E. M. Fisher, Y. Gao, E. Garcia, A. R. George, F. C. Gouldin, C. Hui, B. J. Kirby, S. Leibovich, H. Lipson, M. Y. Louge, J. L. Lumley, M. P. Miller, F. C. Moon, F. K. Moore, S. Mukherjee, M. A. Peck, R. M. Phelan, S. L. Phoenix, S. B. Pope, M. L. Psiaki, E. L. Resler, Jr., A. Ruina, W. Sachse, K. E. Torrance, F. Valero-Cuevas, M. C. H. van der Meulen, H. B. Voelcker, K. K. Wang, Z. Warhaft, C. H. K. Williamson, N. Zabaras, A. Zehnder, K. M. Zhang

**MAE 1110 Naval Ship Systems (also NAVS 2020)**

Fall. 3 credits.

For description, see NAVS 2020.

**MAE 1130 Introduction to Computer-Aided Manufacture (CAM)**

Fall, approx. eight weeks (total 15 hrs. of instruction and 15 hrs. of lab). 1 credit, Limited enrollment. Prerequisites: MAE 2250 or equivalent experience and completion of Emerson Lab Product Realization Facility's CNC seminars: An Introduction to CNC Machining and CNC Programming; or permission of instructor.

Completes the introduction to the fundamentals of computer-aided manufacture (CAM) seminars through the use of computer numerical control (CNC) programming. The course is the hands-on component of the three-part series on CAM. Provides practical applications of the use of G codes and solid modeling software, CNC mill and/or lathe setup, tool selection, and operation. The course is required for students wishing to use the CNC equipment in the Emerson Lab's Product Realization Facility for team or research projects. May not be used to fulfill any MAE requirement.

**MAE 1170 Introduction to Mechanical Engineering (also ENGRI 1170)**

Fall. 3 credits. 2 lec and 1 lab per week.

Course in Introduction to Engineering series. For description, see ENGRI 1170.

**MAE 1270 Introduction to Entrepreneurship and Enterprise Engineering (also ENGRI 1270)**

Spring. 3 credits. Open to all Cornell students regardless of major. Prerequisites: none.

For description, see ENGRI 1270.

**MAE 2120 Mechanical Properties and Selection of Engineering Materials**

Spring; may be offered in summer. 3 credits. Prerequisites: ENGRD/TAM 2020 (Statics) with minimum of C– (strictly enforced); MATLAB programming at level of CS 1112 or CS 1132.

Mechanics of deformable bodies and a reinforcement of the concept of "simple engineering elements" for mechanical analysis associated with design. Introduction to the broad range of properties and behaviors of engineering materials as they relate to mechanical performance. Emphasis is placed on general states of stress and strain, on elasticity and combined loading effects. Failure criteria including yielding, buckling, fracture, fatigue and environmental effects are developed. A general introduction to the function/constraints/objectives approach to material selection associated with mechanical design is provided with candidate material systems coming from metals, polymers, ceramics and/or composites. A general overview of material processing is presented within this context of material selection.

**MAE 2210 Thermodynamics (also ENGRD 2210)**

Fall, spring, may be offered in summer. 3 credits. Prerequisites: MATH 1920 Calculus for Engineers and PHYS 1112 Physics I, Mechanics, or permission of instructor.

For description, see ENGRD 2210.

**MAE 2250 Mechanical Synthesis**

Spring. 4 credits. Prerequisite: ENGRD 2020. Pre- or corequisites: ENGRD 2030 and 2210. Lab fee.

Hands-on introduction on the product design process, from conceptualization through prototype construction and testing. Design projects provide experience in basic prototyping skills using machine tools. Mechanical dissection used to demonstrate successful product design and function. Basic instruction in CAD and technical sketching.

**MAE 3050 Introduction to Aeronautics**

Fall. 3 credits. Prerequisite: TAM/ENGRD 2030. Pre- or corequisites: one of the following thermodynamics classes: ENGRD 2210 or BEE 2220 and one of the following fluid mechanics classes: MAE 3230 or CHEME 3230 or BEE 3310 or CEE 3310; upper-level engineers or permission of instructor.

Introduction to aerodynamic design of aircraft. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Calculation of lift and drag for aircraft. Analysis of aerodynamic performance. Introduction to stability and control.

**MAE 3060 Spacecraft Engineering**

Spring. 3 credits. Prerequisite: ENGRD 2030 or junior or senior MAE or ECE students or permission of instructor.

Introduction to spacecraft engineering from satellite design through launch to orbital operation. Topics covered include space missions, space environment, orbital mechanics, systems engineering, and satellite design. Most spacecraft subsystems are introduced including rocket theory, attitude determination and control, thermal design, and communications. Earth-orbiting and interplanetary satellites are considered. Discussions of current problems and trends in spacecraft operation and development.

**MAE 3120 Mechanical Properties of Materials, Processing, and Design (also MSE 4020, 5820)**

Fall. 4 credits.

For description, see MSE 4020.

**MAE 3130 Atomic and Molecular Structure of Matter (also MSE 2060, MSE 5810)**

Spring. 4 credits.

For description, see MSE 2060.

**MAE 3230 Introductory Fluid Mechanics**

Fall; usually offered in summer through Engineering Cooperative Program. 4 credits. Prerequisites: ENGRD 2020 and ENGRD 2030 and pre- or co-registration in ENGRD 2210, or permission of instructor. Limited to ME majors and those officially registered for the AE or ME minor.

Topics include physical properties of fluids, hydrostatics, conservation laws using control volume analysis and using differential analysis, Bernoulli's equation, potential flows, simple viscous flows (solved with Navier-Stokes equations), dimensional analysis, pipe flows, boundary layers. Introduction to compressible flow.

**MAE 3240 Heat Transfer**

Spring; usually offered in summer through Engineering Cooperative Program. 3 credits. Prerequisite: MAE 3230 or permission of instructor.

Topics include discussion of steady and unsteady heat conduction; forced and free convection; external and internal flows; radiation heat exchange; and heat exchangers and boiling.

**MAE 3250 Analysis of Mechanical and Aerospace Structures**

Fall; usually offered in summer through Engineering Cooperative Program. 3 credits. Prerequisites: ENGRD 2020 and MAE 2120.

Topics in mechanics of materials applied to analysis and design of structural components encountered in mechanical and aerospace systems, including multiaxial stress states, statically indeterminate structures, torsion and bending of nonsymmetric or curved members, stability and stress concentrations. Solution strategies include both analytical and finite element methods.

**MAE 3260 System Dynamics**

Spring; usually offered in summer through Engineering Cooperative Program. 4 credits. Prerequisite: MATH 2930, MATH 2940, ENGRD 2030; junior standing.

Dynamic behavior of mechanical systems: modeling, analysis techniques, and applications; vibrations of single- and multi-degree-of-freedom systems; feedback control systems. Computer simulation and experimental studies of vibration and control systems.

**MAE 3272 Mechanical Property and Performance Laboratory**

Spring. 2 credits. Prerequisites: MAE 2120, 3250.

This course provides an introduction to the experimental methods, instrumentation, and data analyses associated with material property determination and mechanical performance of materials. Emphasis is placed on integration of theory and analysis with experimental methods.

**MAE 3780 Mechatronics**

Fall. 3 credits. Prerequisite: MATH 2930, PHYS 2213, or permission of instructor.

At the intersection of mechanical and electrical engineering, Mechatronics involves technologies necessary to create automated systems. This course introduces students to the functional elements of modern controlled dynamic systems. Topics include analog circuits (both passive and active components); filter design; diodes; transistors, MOSFETs and power amplification; pulse width modulation; transduction; mechanical and electro-mechanical devices such as electromagnetic systems; piezoelectric and shape memory material transduction; gear trains; optical encoders; discretization; aliasing; and microprocessors and programming. Lab experiments culminate in the design, fabrication, and programming of a microprocessor-controlled robotic vehicle, which laboratory groups enter into a class-wide competition.

**[MAE 4000 Components and Systems: Engineering in a Social Context (also STS 4001)**

Spring. 3 credits. Prerequisites: upper-class standing, two years of college physics. Offered alternate years; next offered 2009–2010.

Addresses, at a technical level, broader questions than are normally posed in the traditional engineering or physics curriculum. Through the study of individual cases such as the Strategic Defense Initiative (SDI), the National Missile Defense, supersonic transport, and the automobile and its effect on the environment, the course investigates interactions between the scientific, technical, political, economic, and social forces that are involved in the development of engineering systems. "Senior Design Elective" if students sign up for the corresponding section of MAE 4291. Co-meets with MAE 5000.]

**MAE 4020 Wind Power**

Fall. 3 credits. Prerequisite(s): MAE 3230 (or equivalent) or MAE 3050, MAE 3250.

Main features of energy conversion by wind turbines. Emphasis on characterization of the atmospheric boundary layer, aerodynamics of horizontal axis wind turbines, and performance prediction. Structural effects, power train considerations, siting and wind farm planning. "Senior Design Elective" if M.E. seniors enroll in corresponding section of MAE 4291.

**MAE 4040 Materials Selection for Clean Mechanical Designs**

Spring. 3 credits. Prerequisites: MAE 2120, MAE 3250. Pre- or corequisite MAE 3272. "Senior Design Elective" for M.E. students who enroll in corresponding section of MAE 4291. Offered alternate years.

Advanced material selection concepts, which build off of the fundamentals of materials index developed in MAE 2120 and 3250, including process and shape selection, hybrid materials, and industrial design. Includes a brief overview of current clean technologies and the basics of life cycle and environmentally conscious design. Two main themes are: (1) application of materials-selection basics and concepts of life-cycle design to current design limitations associated with various clean technologies and (2) determination of the mechanical properties of various emerging green materials.

**[MAE 4140 Mechanics of Lightweight Vehicles**

Fall. 3 credits. Prerequisites: MAE 2120, 3250, and 3272 or equivalent; senior standing in MAE. "Senior Design Elective" for M.E. students who enroll in corresponding section of MAE 4291. Offered alternate years; next offered 2009–2010.

Covers fundamentals of vehicle mechanics for several classes of vehicles (bicycles, light cars, airframes). Topics include: types of vehicle structures; pertinent aspects of mechanical behavior including elastic and inelastic responses; static and dynamic behavior of vehicles under elastic loading; and mechanics of crashworthiness. Lectures cover essential background material for understanding of vehicle mechanics. Labs provide hands-on experiences in the major components of the course.]

**MAE 4150 GPS: Theory and Design (also ECE 4150)**

Fall. 4 credits. Prerequisites: 3000-level engineering course with advanced math content (e.g., ECE 3030 or MAE 3260).

For description, see ECE 4150.

**MAE 4170 Introduction to Robotics: Dynamics, Control, Design**

Spring. 3 credits. Prerequisites: engineering math at level of MATH 2930 and MATH 2940 (Engineering Mathematics); some course in dynamics at level of TAM/ ENGRD 2030 (Dynamics); familiarity with control concepts typical of MAE 3260 (System Dynamics).

Introductory course in the analysis and control of mechanical manipulators and related robotic machines. Topics include spatial descriptions and transformations, manipulator kinematics and inverse kinematics. Design of end effectors, differential relationships and static forces, manipulator dynamics, trajectory generation, sensors and actuators. Design of PD controllers, trajectory control, and compliant motion control. Simulation and design using MATLAB and multi-body codes are used. Co-meets with MAE 5170.

**MAE 4230 Intermediate Fluid Dynamics**

Spring. 3 credits. Prerequisite: MAE 3230 (Introductory Fluid Mechanics) or CEE 3310/BEE 3310, CHEME 3230 or permission of instructor.

This course builds on the foundation of MAE 3230. Emphasis is placed on both the fundamental principles and numerical calculation of real flows (both engineering and environmental) using a computational fluid dynamics package. Topics include some exact solutions to the Navier-Stokes equations, boundary layers, wakes and jets, separation, convection, fluid instabilities, and turbulence. "Senior Design Elective" if M.E. seniors enroll in the corresponding section of MAE 4291. Co-meets with MAE 5230.

**MAE 4250 FSAE Automotive Design Project**

Fall, spring. Usually 3 credits: 3 for team members or 4 for team leaders. Prerequisite: MAE or ECE juniors and seniors or permission of instructor.

Project course to research, design, build, develop, and compete with a Formula SAE car for intercollegiate competition. Students work in interdisciplinary teams using concurrent engineering and systems engineering principles applied to complex mechanical, electromechanical, and electronic systems. "Senior Design Elective" if M.E. seniors enroll in the corresponding section of MAE 4291.

**MAE 4272 Fluids/Heat Transfer Laboratory**

Fall. 3 credits. Fulfills technical-writing requirement. Prerequisites: MAE 3230, 3240.

Laboratory exercises in fluid mechanics and the thermal sciences. Measurements of flame temperature, pressure, heat transfer, viscosity, lift and drag, fluid-flow rate, effects of turbulence, airfoil stall, flow visualization, and spark ignition engine performance. Instrumentation, techniques and analysis, and interpretation of results. Biweekly written assignments with extensive feedback.

**MAE 4291 Supervised Senior Design Experience**

Fall, spring. Minimum of 1 or 3 credits depending on section chosen. Prerequisite: senior standing or permission of instructor; taken concurrently or after MAE 4280. Letter grades only.

Substantial design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints. Sections of this course satisfy the BS ME senior design requirement. They are offered in conjunction with a course designated as "Senior Design Elective" (MAE 4000, 4020, 4040, 4140, 4230, 4700, 4860) or are directed by a faculty member as an individual or a team design exercise. Consult www.mae.cornell.edu for enrollment details.

**MAE 4300 Professional Practice in Mechanical Engineering**

Fall. 2 credits. Prerequisite: senior standing in MAE or permission of instructor. This course is required for M.E. seniors, replacing MAE 428.

Professional practice and broader impacts of the mechanical engineering profession are presented through a series of lectures and invited talks, supplemented by assignments and projects. Topics include: professional ethics, product liability, intellectual property, career/educational paths, contemporary issues facing mechanical engineers, and engineering successes and failures, along with the global, societal, environmental and/or economic aspects and impact of engineering.

**[MAE 4490 Combustion Engines and Fuel Cells**

Spring. 3 credits. Prerequisites: ENGRD 2210 and MAE 3230. Offered alternate years; next offered 2009–2010.

Introduction to reciprocating combustion engines and fuel cells, with emphasis on the application of thermodynamic and fluid-dynamic principles affecting their performance. Chemical equilibrium and kinetics, electrochemistry, thermodynamic limits on performance, deviations from ideal processes, engine breathing, combustion, knock. Formation and control of undesirable exhaust emissions.]

**MAE 4530 Computer-Aided Engineering: Applications to Biomedical Processes (also BEE 4530)**

Spring. 3 credits. Fulfills technical elective requirement for MAE students. Prerequisite: Heat and Mass Transfer (BEE 3500, Biological and Environmental Transport Processes, or CHEME 3240, Heat and Mass Transfer, or MAE 3240, Heat Transfer) or equivalent.

For description, see BEE 4530.

**MAE 4550 Introduction to Composite Materials (also CEE 4770, MSE 5550, TAM 4550)**

Fall. 4 credits.

For description, see TAM 4550.

**MAE 4570 Space Systems and National Security**

Fall. 3 credits. Prerequisite: upper-level standing and MATH 2930 and ENGRD 2030 or permission of instructor.

This course is intended to provide an overview of the implications of space for national security and vice versa. It will consider subjects such as an overview of United States space usage, how the United States monitors what is in space, specific national security applications of space systems, vulnerabilities of space systems, anti-satellite and space weapons, the relationship between missile defenses and space weapons, and the current debate over how the United States can best preserve the benefits it receives from the use of space.

**MAE 4580 Introduction to Nuclear Science and Engineering (also ECE/ TAM 4130)**

Fall. 3 credits. Prerequisites: PHYS 2214 and MATH 2940.

For description, see TAM 4130.

**MAE 4590 Introduction to Controlled Fusion: Principles and Technology (also AEP/ECE 4840)**

Spring. 3 credits. Prerequisites: PHYS 1112, 2213, and 2214, or equivalent background in electricity and magnetism and mechanics. Intended for seniors and graduate students in engineering and the physical sciences. Offered alternate years.

For description, see ECE 4840.

**MAE 4610 Entrepreneurship for Engineers (also ENGRG 4610, ORIE 4152)**

Fall. 3 credits. Limited enrollment. Prerequisite: upper-level engineers or permission of instructor.

Develops skills necessary to identify, evaluate, and begin new business ventures. Topics include intellectual property, competition, strategy, business plans, technology forecasting, finance and accounting, and sources of capital. A rigorous, quantitative approach is stressed throughout, and students create financial documents and plans, analyze human resource models, and work with sophisticated valuation methods, complicated equity structures, and legal and business documents. As such, this course represents the "red meat" of entrepreneurship, and the soft skills are left for other courses. Course work consists of discussions, assignments, and the preparation and presentation of a complete business plan.

**[MAE 4630 Neuromuscular Biomechanics (also BME 4630)]**

**MAE 4640 Orthopaedic Tissue Mechanics (also BME 4640)**

Spring. 3 credits. Prerequisites: ENGRD 2020 Mechanics of Solids and MAE 3250 Mechanical Design and Analysis or permission of instructor. Co-meets with MAE 5640. Offered alternate years.

Applications of mechanics and materials principles to orthopaedic tissues. Physiology of bone, cartilage, ligament, and tendon and how these properties relate to mechanical function. Mechanical behavior of skeletal tissues in the laboratory. Functional adaptation of these tissues to their mechanical environment. Tissue engineering of replacement structures.

**MAE 4660 Biomedical Engineering Analysis of Metabolic and Structural Systems (also BME 4010)**

Fall. 3 credits. Prerequisites: ENGRD 2020 Mechanics of Solids and previous course work in biology or permission of instructor.

For description, see BME 4010.

**MAE 4700 Finite Element Analysis for Mechanical and Aerospace Design**

Fall. 3 credits. Fulfills senior design requirement for MAE students. Limited enrollment. Prerequisite: senior standing or permission of instructor. Evening exams. Term project.

Introduction to linear finite element static and dynamic analysis for discrete and distributed mechanical and aerospace structures. Prediction of load, deflection, stress, strain, and temperature distributions. Major emphasis on underlying mechanics and numerical methods. Introduction to computational aspects via educational and commercial software (such as MATLAB and ANSYS). Selected mechanical and aerospace applications in the areas of trusses, beams, frames, heat transfer (steady state and transient), and elasticity (static and dynamic). Term project. "Senior Design Elective" if M.E. seniors enroll in the corresponding section of MAE 4291. Co-meets with MAE 5700.

**MAE 4770 Engineering Vibrations**

Spring. 3 credits. Pre- or corequisite: MAE 3260 or permission of instructor.

Lumped element, distributed parameter, and mixed structural vibratory systems are examined. Equations of motion are derived from Newton's law and Lagrange's equations. Eigenanalysis, free and forced responses, and frequency/time domain solutions are considered. Vibration absorbers, isolators, and vibration suppression control systems using feedback approaches also are investigated. Co-meets with MAE 5770.

**MAE 4780 Feedback Control Systems (also CHEME/ECE 4720)**

Fall. 4 credits. Prerequisites: CHEME 3720 or MAE 3260 or permission of instructor.

Analysis techniques, performance specifications, and analog-feedback-compensation methods for single-input, single-output, linear, time-invariant systems. Laplace transforms and transfer functions are the principal mathematical tools. Design techniques include root-locus and frequency response methods. Includes laboratory that examines modeling and control of representative dynamic processes. Co-meets with MAE 5780.

**MAE 4860 Automotive Engineering**

Spring. 3 credits. Prerequisites: ENGRD 2020 or permission of instructor.

Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis on automobiles. Engines, transmissions, suspension, brakes, and aerodynamics will be discussed. The course uses first principles and applies them to specific systems. The course is highly quantitative, using empirical and analytical approaches. "Senior Design Elective" if M.E. seniors enroll in the corresponding section of MAE 4291.

**MAE 4900 Special Investigations in Mechanical and Aerospace Engineering**

Fall, spring. 4 variable credits. Prerequisite: undergraduate standing and permission of instructor.

Intended for an individual student or a small group of students who want to pursue a particular analytical or experimental investigation outside of regular courses or for informal instruction supplementing that given in regular courses.

**MAE 4980 Teaching Experience in Mechanical Engineering**

Fall, spring. 3 variable credits. Prerequisite: permission of instructor.

Students serve as teaching assistants in Cornell mechanical engineering classes or in local middle school technology classes. Cannot be used to fulfill M.E. technical elective or M.E. major elective requirements but may be approved as advisor-approved elective. May not be used toward satisfying M.E. minor.

**[MAE 5000 Components and Systems: Engineering in a Social Context**

Spring. 3 credits. Prerequisites: graduate standing or permission of instructor, two years of college physics. Offered alternate years; next offered 2009–2010.

Co-meets with MAE 4000. For description, see MAE 4000.]

**MAE 5010 Future Energy Systems**

Spring. 3 credits. Prerequisites: ENGRD 2210 (Thermodynamics) or equivalent. Recommended: MAE 3230 (Introductory Fluid Mechanics), MAE 3240 (Heat Transfer), or equivalents; open to graduate or senior standing or permission of instructor.

Critically examines the technology of energy systems that will be acceptable in a world faced with global climate change, local pollution, and declining supplies of oil. The focus is on renewable energy sources (wind, solar, biomass), but other non-carbon-emitting sources (nuclear) and lowered-carbon sources (co-generative gas turbine plants, fuel cells) also are studied. Both the devices and the overall systems are analyzed.

**[MAE 5060 Aerospace Propulsion Systems**

Spring. 3 credits. Prerequisite: MAE 3050 (Introduction to Aeronautics) or permission of instructor. Offered alternate years; next offered 2009–2010.

Application of thermodynamic and fluid-mechanical principles to design and performance analysis of aerospace propulsion systems. Jet propulsion principles, including gas turbine engines and rockets. Electric propulsion. Future possibilities for improved performance of aerospace propulsion systems.]

**MAE 5070 Dynamics of Flight Vehicles**

Spring. 3 credits. Prerequisites: MAE 3050 (Introduction to Aeronautics) and MAE 3260 (System Dynamics) or permission of instructor. Offered alternate years.

Introduction to stability and control of atmospheric-flight vehicles. Review of aerodynamic forces and methods for analysis of linear systems. Static stability and control. Small disturbance equations of unsteady motion. Dynamic stability of longitudinal and lateral-directional motions; transient response. At the level of *Flight: Stability and Automatic Control* by Nelson.

**[MAE 5130 Mechanical Properties of Thin Films (also MSE 5120)**
Spring. 3 credits. Offered alternate years; next offered 2009–2010.
For description, see MSE 5120.]

**MAE 5170 Introduction to Robotics: Dynamics, Control, Design**
Spring. 3 credits. Graduate version of MAE 4170. Co-meets with MAE 4170.
For description, see MAE 4170.

**[MAE 5200 Dimensional Tolerancing in Mechanical Design**
Fall, seven-week half term. 2 credits. Prerequisites: MAE 2250 or an equivalent CAD–based design course, plus 2.5 years of engineering mathematics through probability and statistics. Next offered 2009–2010.
Designers use dimensional tolerances to limit spatial variations in mechanical parts and assemblies; the primary goals are interchangeability in assembly, performance, and cost. This course covers traditional limit tolerances briefly but focuses mainly on modern geometric tolerances and their role in assembly control. Students learn how to represent assemblies in terms of mating and relational constraints, design tolerances, and inspection gauges from part and assembly specifications, and understand the limitations and future directions of tolerancing technology.]

**MAE 5210 Theory of Linear Systems (also ECE 5210)**
Fall. 3 credits. Prerequisite: ECE 3200 or permission of instructor. Recommended: good background in linear algebra and linear differential equations.
State-space and multi-input–multi-output linear systems in discrete and continuous time. The state transition matrix, the matrix exponential, and the Cayley-Hamilton theorem. Controllability, observability, stability, realization theory. At the level of *Linear Systems* by Kailath.

**MAE 5230 Intermediate Fluid Dynamics**
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Intended for M.Eng. students who wish to take a fluid dynamics course including implementation of commercial computational fluid dynamics packages. Complements material in MAE 6010 and 6020. For description of topics covered, see MAE 4230. Includes a 1-credit CFD design project due at the end of the semester. Students desiring to write their own computational fluid dynamics software should consider one or more of MAE 6360, 7360, and 7370. Co-meets with MAE 4230.

**MAE 5240 Physics of Micro- and Nanoscale Fluid Mechanics (also CHEME 6240)**
Fall. 3 credits. Prerequisite: undergraduate fluid or continuum mechanics (e.g., MAE 3230) or permission of instructor.
Introduction to fluid mechanics in micro- and nanofabricated devices. Physicochemical hydrodynamics, electrokinetic effects, capillarity, continuum breakdown, micro- and nanofluidic applications in chemistry and life sciences. Co-meets with MAE 6240.

**MAE 5430 Combustion Processes**
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.
An introduction to combustion and flame processes, with emphasis on fundamental fluid dynamics, heat and mass transport, and reaction-kinetic processes that govern combustion rates. Topics covered include thermochemistry, kinetics, vessel explosions, laminar premixed and diffusion flames, and droplet combustion. Optional topics may include complex combustion systems, turbulent flames, fuel cells, or combustion of solids.

**MAE 5459 Energy Seminar I (also ECE 5870)**
Fall. 1 credit.
For description, see ECE 5870.

**MAE 5469 Energy Seminar II (also ECE 5880)**
Spring. 1 credit.
For description, see ECE 5880.

**[MAE 5630 Neuromuscular Biomechanics]**

**MAE 5640 Orthopaedic Tissue Mechanics**
Spring. 3 credits. Graduate version of MAE 4640. Offered alternate years.
For description see MAE 4640.

**[MAE 5650 Biomechanical Systems—Analysis and Design (also BME 5650)]**

**MAE 5680 Soft Tissue Biomechanics**
Fall. 3 credits.
For description, see BME 5810.

**MAE 5700 Finite Element Analysis for Mechanical and Aerospace Design**
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor. Evening exams. Term project. Graduate version of MAE 4700 requires additional programming assignment. Co-meets with MAE 4700.
For description, see MAE 4700.

**[MAE 5710 Applied Dynamics**
Fall. 3 credits. Prerequisites: graduate standing, seniors with ENGRD/TAM 203, MAE 3260 or permission of instructor. Next offered 2009–2010.
Introduces multibody dynamics; dynamics of rigid bodies; Newton-Euler methods, Lagrangian dynamics, principle of virtual power (Kane-Jourdain methods); and applications to robotics, space dynamics of satellites, electro-mechanical systems. Introduction to multibody simulation using Working Model.]

**MAE 5770 Engineering Vibrations**
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Graduate version of MAE 4770. Co-meets with MAE 4770.
For description, see MAE 4770.

**MAE 5780 Feedback Control Systems**
Fall. 4 credits. Graduate version of MAE 4780. Co-meets with MAE 4780.
For description, see MAE 4780.

**MAE 5910 Applied Systems Engineering (also CEE/CS 5040, ECE 5120, ORIE 5140, SYSEN 5100)**
Fall. 3 credits. Prerequisites: senior or graduate standing in engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by course instructor.
For description, see SYSEN 5100.

**MAE 5920 System Architecture, Behavior, and Optimization (also CEE/CS 5050, ECE 5130, ORIE 5142, SYSEN 5200)**
Spring. 3 credits. Prerequisites: senior or graduate standing and completion of Applied Systems Engineering 1 (CEE 5240, CS 5040, ECE 5120, ORIE 5140, MAE 5910, or SYSEN 5100) or permission of instructor.
For description, see SYSEN 5200.

**MAE 5930 Systems Engineering for the Design and Operation of Reliable Systems (also SYSEN 5300)**
Fall. 3 credits. Prerequisites: MAE 5910 and either ENGRD 2700 or CEE 3040.
For description, see SYSEN 5300.

**MAE 5949 Enterprise Engineering Colloquium (also ORIE 9100–9101)**
Fall, spring. 1 credit each semester. Usually S–U grades.
For description, see ORIE 9100–9101.

**MAE 6010 Foundations of Fluid Dynamics and Aerodynamics**
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
Foundations of fluid mechanics from an advanced viewpoint, including formulation of continuum fluid dynamics; surface phenomena and boundary conditions at interfaces; fundamental kinematic descriptions of fluid flow, tensor analysis, derivation of the Navier-Stokes equations and energy equation for compressible fluids; and sound waves, viscous flows, boundary layers, and potential flows.

**MAE 6020 Fluid Dynamics at High Reynolds Numbers**
Spring. 4 credits. Prerequisite: MAE 6010.
Analysis and discussion of a wide range of specific flows and flow regimes characterized by high Reynolds number are provided. Potential flows, conformal transformations, slender-body theory, and Kelvin's impulse are included. Laminar viscous flows are studied, including fully diffused flows, exact solutions, and boundary layers. Compressible flows are treated, including propagation and viscous decay of sound and shock waves and their decay, and the method of characteristics for analysis of such problems. Stratified flows, especially gravity and capillary waves, are analyzed. Stability of a particular high Reynolds number flow is discussed. Finally, certain low Reynolds number flows associated with creeping motions or with ultra-small scale are described.

**MAE 6060 Spacecraft Dynamics and Mission Design**
Spring. 3 credits, Prerequisites: graduate standing or permission of instructor; background in linear algebra at level of MATH 2940 is required; some experience with MATLAB is expected. Offered alternate years.
The focus is on spacecraft attitude dynamics and its application in core space-systems areas: mission design, operations, and autonomy. Also introduces the problem of attitude estimation and treats aspects of guidance, navigation, and control unique to the context of space mission design. Readings and lectures include examples based on flight data.

**[MAE 6080 Physics of Fluids**
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years; next offered 2009–2010.

Behavior of an ideal gas is considered at the microscopic level. Introduction to kinetic theory—the velocity distribution function, molecular collisions, and Boltzmann equation; to quantum theory—postulates of quantum mechanics, rigid rotator, harmonic oscillator, one-electron and multi-electron atoms and molecular structure; and to statistical mechanics—the partition function, relation to thermodynamics, calculations of thermodynamic properties.]

**MAE 6240 Physics of Micro- and Nanoscale Fluid Mechanics**

Fall. 4 credits. Prerequisite: undergraduate fluid or continuum mechanics (e.g., MAE 3230) or permission of instructor. Graduate version of MAE 5240. Includes additional 1-credit design project. Co-meets with MAE 5240.

For description, see MAE 5240.

**[MAE 6270 Experimental Methods in Fluid Dynamics (also CEE 6370)**

Spring. 4 credits. E. A. Cowen. Next offered 2009–2010.

For description, see CEE 6370.]

**MAE 6310 Turbulence and Turbulent Flows**

Fall. 4 credits. Prerequisite: MAE 6010 (Foundations of Fluid Dynamics and Aerodynamics), graduate standing, or permission of instructor.

Topics include the dynamics of buoyancy and shear-driven turbulence, boundary-free and bounded shear flows, second-order modeling, the statistical description of turbulence, turbulent transport, and spectral dynamics.

**[MAE 6320 Multiphase Turbulence: Particulates, Drops, and Polymer Suspensions]**

**[MAE 6430 Computational Combustion**

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. S. B. Pope. Next offered 2009–2010.

Examines laminar and turbulent flames and the fundamental chemical and transport processes involved. Emphasis is on using computational tools (Chemkin and Fluent) to calculate flame properties, which are compared to experimental data. Topics covered include thermodynamic equilibrium, chemical kinetics, reactor studies, conservation equations, transport properties, laminar premixed and non-premixed flames, turbulent jets, turbulence modeling, and PDF models of non-premixed turbulent combustion. A knowledge of combustion at the level of MAE 5430, Combustion Processes, is useful but not required.]

**[MAE 6450 Turbulent Reactive Flow**

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years; Next offered 2009–2010.

Large turbulent reactive flows occur in combustion devices, the chemical process industry, the atmosphere, oceans, and elsewhere. In the last decade, substantial progress has been made in the understanding of these flows, through both experimental and computational approaches. This course focuses on turbulent combustion and describes the different phenomena involved, the basic processes and governing equations, experimental techniques and observations, and a range of modeling approaches. Class meets, on average, twice per week.]

**[MAE 6480 Air Quality and Atmospheric Chemistry (also EAS 6480)**

Fall. 3 credits. Prerequisites: first-year chemistry and thermodynamics (or equivalent) and fluid mechanics (or equivalent); graduate standing or permission of instructor. Next offered 2009–2010.

Factors determining air quality and effects of air pollutants on public health, ecological systems and global climate change. Students will examine the source-to-receptor relationship of major air pollutants with an emphasis on the physical and chemical fundamentals of atmospheric transport and transformation. Topics include photochemical smog, atmospheric aerosols, atmospheric transport and deposition, emissions from energy systems, introduction to air quality monitoring and modeling, and air quality management.]

**MAE 6500 Evolutionary Computation and Design Automation (also CS 7726)**

Fall. 4 credits. Not offered every year..

For description, see CS 7726.

**[MAE 6510 Conduction and Radiation Heat Transfer**

Fall, weeks 1–7. 2 credits. Prerequisite: graduate standing; undergraduates by permission of instructor. Next offered 2009–2010.

An advanced treatment of heat conduction and thermal radiation from a theoretical perspective. Topics include: development of the conductive transport equation in integral and differential forms; the transport theorem; solutions for steady state and transient conditions; moving boundary effects including melting and solidification; introduction to radiation including black body and gray body radiation, the radiative transport equation and radiation in an absorbing and scattering medium. At the level of *Conduction Heat Transfer*, by V. Arpaci, and *Radiation Heat Transfer*, by E. M. Sparrow and R. D. Cess.]

**[MAE 6520 Convection Heat Transfer**

Fall, weeks 8–14. 2 credits. Prerequisite: graduate standing; undergraduates by permission of instructor. Next offered 2009–2010.

An advanced treatment of convection heat transfer from a theoretical perspective. Topics include: conservation of linear momentum in integral and differential forms; boundary layer flows with emphasis on laminar conditions (some introduction to turbulence also included); internal and external flows; forced and free convection; theoretical solutions and scale analysis. At the level of *Convection Heat Transfer,* by A. Bejan, and *Convective Heat and Mass Transfer*, by W. M. Kays et al.]

**MAE 6550 Composite Materials (also TAM/MSE 6550)**

Spring. 4 credits.

For description, see TAM 6550.

**[MAE 6560 Nanoscale Energy Transport and Conversion**

Spring. 4 credits. Prerequisites: undergraduate heat transfer recommended (e.g., MAE 3240) or permission of instructor. Next offered 2009–2010.

As electronic, optoelectronic, photonic and fluidic devices shrink from the microscale down to the nanoscale, the mechanisms for transmitting heat, light and energy become dramatically different. This course aims to provide a detailed look at thermal, electrical and optical energy transport and conversion mechanisms at the nanoscale. Topics to be covered include: a brief review of macroscopic heat transfer with emphasis on limits of macroscopic models, microscopic picture of energy carriers, material waves, energy quantization and energy states in solids, statistical thermodynamics and probability distribution functions as related to thermal energy storage, energy transport by waves and classical particle descriptions of transport processes and energy conversion and exchange processes between carriers.]

**[MAE 6630 Neural Control (also BME 6630)]**

**[MAE 6640 Mechanics of Bone (also BME 6640)**

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years; next offered 2009–2010.

Covers current methods and results in skeletal research, focusing on bone. Topics include skeletal anatomy and physiology, experimental and analytical methods for determination of skeletal behavior, mechanical behavior of bone tissue, and skeletal functional adaptation to mechanics.]

**MAE 6650 Principles of Tissue Engineering (also BME/MSE 6650)**

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.

For description, see BME 6650.

**[MAE 6750 System Identification and Control]**

**[MAE 6760 Model-Based Estimation**

Spring. 4 credits. Prerequisites: linear algebra, differential equations, and MATLAB programming. Open to M.S./Ph.D. students or permission of instructor. Offered alternate years; next offered 2009–2010.

Covers a variety of ways in which models and experimental data can be used to estimate model quantities that are not directly measured. The two main estimation methods that are presented are least-squares estimation for general problems and Kalman filtering for dynamic systems problems. Techniques for linear models are taught as are techniques for nonlinear models. Both theory and application are presented.]

**MAE 6780 Multivariable Control Theory**

Spring, 4 credits. Prerequisites: MAE 4780 or 5780 or ECE 4720 (Feedback Control Systems) and MAE 5210 (Theory of Linear Systems), or permission of instructor; strong background in classical control, linear algebra, and state space models.

Introduction to multivariable feedback control theory in both time and frequency domain. Primary topics include state space methods, model based compensators, performance and robustness of multivariable systems, model reduction, Linear Quadratic and H-infinity optimal control, and random processes and Kalman filtering for control. Additional topics at the discretion of the instructor include uncertainty management and robust control, discrete time control, optimal control, and nonlinear control.

**MAE 6900 Special Investigations in Mechanical and Aerospace Engineering**

Fall, spring. Variable credit. Prerequisite: candidacy for the M.Eng. degree in mechanical or aerospace engineering or approval of faculty member offering project.

Project-based course in the area of mechanical or aerospace engineering under the guidance of a faculty member.

**MAE 6950 Special Topics in Mechanical and Aerospace Engineering**

Fall, spring. Credit TBA. Prerequisites: graduate standing and permission of instructor.

Special lectures by faculty members on topics of current research.

**MAE 7110 X-Ray Diffraction Methods for Engineering Materials**

Fall. 4 credits. Prerequisites: graduate standing or permission of instructor.

We develop a general understanding of diffraction methods employed for understanding the state of crystalline materials. The focus will be on x-ray diffraction and the determination of crystal orientation and lattice strains. We conduct diffraction experiments at the CCMR x-ray facility and examine synchrotron x-ray data. We develop MATLAB–based methods for reducing diffraction data and extracting distributions of orientation and lattice strain.

**MAE 7120 Mechanics of Materials with Oriented Microstructures**

Spring. 4 credits. Prerequisites: TAM 6630 or equivalents. Offered alternate years.

The focus of this course is the evaluation of mechanical properties from knowledge of the material microstructure, with attention to anisotropic elastic and plastic behaviors. Topics include mathematical and mechanics preliminaries; mathematical foundations of orientations, including parameterizations, symmetries, and fibers; construction and sampling of orientation distributions; hypotheses used to link macro and micro length scales; methods for evaluation of effective elastic and plastic moduli; evolution of orientations and orientation distributions with deformation. Applications to polycrystalline solids (metal alloys and minerals), composite materials, biomaterials (soft tissues), and polymers.

**MAE 7140 Computational Sensorics: Information Technologies for Complex Continuum Systems**

Spring. 4 credits. Prerequisite: exposure to computational mathematics.

Examples of industrial control of continuum systems; mathematical preliminaries; data-driven inverse problems; data mining and knowledge discovery in continuum systems; Bayesian computation; optimal and robust control; model reduction; uncertainty modeling and stochastic optimization; Sensors and sensor-networks.

**MAE 7150 Atomistic Modeling of Materials**

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.

Intended for graduate students in engineering, physics, and chemistry with interests in the simulation of materials at the atomic scale using academic and commercial software. Emphasis is given to models of interatomic forces from Lennard-Jones models to self-consistent all-electron solution of the quantum mechanical problem. Specific topics include: energy models, density functional theory and the total-energy pseudopotential method, Monte Carlo and molecular dynamics simulations, free energy and phase transitions, fluctuations and transport properties, first-principles MD, Ab-initio thermodynamics and structure prediction, coarse-graining methods and mesoscale models. The course includes advanced applications of materials to nanotechnology. The material covered is self-contained, but an earlier exposure to quantum mechanics and solid state physics is desirable.

**[MAE 7340 Analysis of Turbulent Flows**

Spring. 4 credits. Prerequisite: MAE 6010 Foundations of Fluid Dynamics and Aerodynamics or permission of instructor. Offered alternate years; next offered 2009–2010.

Study of methods for calculating the properties of turbulent flows. Characteristics of turbulent flows. Direct numerical simulations and the closure problem. Reynolds-stress equation: effects of dissipation, anisotropy, deformation. Transported scalars. Probability density functions (pdfs): transport equations, relationship to second-order closures, stochastic modeling, and the Langevin equation. Large-eddy simulations: filtered and residual motions, Smagorinsky, and dynamic models. This course emphasizes comparison of theory with experiment and includes CFD projects.]

**MAE 7370 Computational Fluid Mechanics and Heat Transfer**

Fall. 4 credits. Prerequisites: graduate standing; advanced course in continuum mechanics, heat transfer, or fluid mechanics; and some MATLAB, C++, or other programming experience.

Numerical methods are developed for the elliptic and parabolic partial differential equations that arise in fluid flow and heat transfer when convection and diffusion are present. Finite-difference, finite-volume, and some spectral methods are considered, together with issues of accuracy, stability, convergence, and conservation. Current methods are reviewed. Emphasis is on steady and unsteady essentially incompressible flows. Assigned problems are solved on a digital computer.

**MAE 7910 Mechanical and Aerospace Research Conference**

Fall, spring. 1 credit each semester. For graduate students involved in research projects. S–U grades only.

Presentations on research in progress by faculty and students.

**MAE 7999 Mechanical and Aerospace Engineering Colloquium**

Fall, spring. 1 credit each semester; credit limited to graduate students. All students and staff are invited to attend.

Lectures by visiting scientists and Cornell faculty and staff members on research topics of current interest in mechanical and aerospace science, especially in connection with new research.

**MAE 8900 Research in Mechanical and Aerospace Engineering**

Credit TBA. Prerequisite: candidacy for M.S. degree in mechanical or aerospace engineering or approval from director.

Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

**MAE 9900 Research in Mechanical and Aerospace Engineering**

Credit TBA. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval from director.

Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

# NUCLEAR SCIENCE AND ENGINEERING

Faculty members in the graduate field of nuclear science and engineering who are most directly concerned with the curriculum include K. B. Cady, D. A. Hammer, R. W. Kay, and V. O. Kostroun.

**NSE 4130 Introduction to Nuclear Science and Engineering (also AEP/CHEME/ECE/TAM 4130, MAE 4580)**

Fall. 3 credits. Prerequisites: PHYS 2214 and MATH 2940.

For description, see TAM 4130.

**NSE 4840 Introduction to Controlled Fusion: Principles and Technology (also AEP/ECE 4840, MAE 4590)**

Spring. 3 credits. Prerequisites: PHYS 1112, 2213, and 2214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students. D. A. Hammer.

For description, see ECE 4840.

**NSE 5450 Energy Seminar (also ECE 5870, MAE 5450)**

Fall, spring. 1 credit; may be taken for credit both semesters. D. A. Hammer.

For description, see ECE 5870.

**NSE 5900 Independent Study**

Fall, spring. 1–4 credits. Letter or S–U grades. Staff.

Independent study or project under guidance of a faculty member.

**NSE 5910 Project**

Fall, spring. 1–6 credits. Staff.

Master of engineering or other project under guidance of a faculty member.

**NSE 6330 Nuclear Reactor Engineering (also AEP 6330)**

Fall. 4 credits. Prerequisite: introductory course in nuclear engineering. Offered on demand. K. B. Cady

The fundamentals of nuclear reactor engineering, reactor sitting and safety, fluid flow and heat transfer, control, environmental effects, and radiation protection.

# OPERATIONS RESEARCH AND INFORMATION ENGINEERING

L. J. Billera, R. G. Bland, K. Caggiano, J. R. Callister, E. Friedman, S. Henderson, P. L. Jackson, R. A. Jarrow, A. Lewis, M. Lewis, W. L. Maxwell, J. A. Muckstadt, N. Prabhu, P. Protter, J. Renegar, S. I. Resnick, R. Roundy, D. Ruppert, P. Rusmevichientong, G. Samorodnitsky, A. Schied, D. Shmoys, É. Tardos, M. J. Todd, H. Topaloglu, L. E. Trotter, Jr., B. W. Turnbull, S. Weber, D. P. Williamson, D. B. Woodard

**ORIE 3120 Industrial Data and Systems Analysis**

Spring. 4 credits. Prerequisite: ENGRD 2700.

Database and statistical techniques for data mining, graphical display, and predictive analysis in the context of industrial systems (manufacturing and distribution). Database techniques include structured query language (SQL), procedural event-based programming (Visual Basic), and geographical information systems. Statistical techniques include multiple linear regression, classification, logistic regression, and time series forecasting. Industrial systems analysis includes factory scheduling and simulation, materials planning, cost estimation, inventory planning, and quality engineering.

**ORIE 3150 Financial and Managerial Accounting**

Fall, spring, summer, and winter. 4 credits.

Covers principles of accounting, financial reports, financial-transactions analysis, financial-statement analysis, budgeting, job-order and process-cost systems, standard costing and variance analysis, and economic analysis of short-term decisions.

**ORIE 3300 Optimization I**

Fall and summer. 4 credits. Prerequisite: MATH 2210 or 2940.

Formulation of linear programming problems and solutions by the simplex method. Related topics such as sensitivity analysis, duality, and network programming. Applications include such models as resource allocation and production planning. Introduction to interior-point methods for linear programming.

**ORIE 3310 Optimization II**

Spring and summer. 4 credits. Prerequisite: ORIE 3300 or equivalent.

A variety of optimization methods stressing extensions of linear programming and its applications but also including topics drawn from integer programming, dynamic programming, and network optimization. Formulation and modeling are stressed as well as numerous applications.

**ORIE 3500 Engineering Probability and Statistics II**

Fall and summer. 4 credits. Prerequisite: ENGRD 2700 or equivalent.

A rigorous foundation in theory combined with the methods for modeling, analyzing, and controlling randomness in engineering problems. Probabilistic ideas are used to construct models for engineering problems, and statistical methods are used to test and estimate parameters for these models. Specific topics include random variables, probability distributions, density functions, expectation and variance, multidimensional random variables, and important distributions including normal, Poisson, exponential, hypothesis testing, confidence intervals, and point estimation using maximum likelihood and the method of moments.

**ORIE 3510 Introductory Engineering Stochastic Processes I**

Spring and summer. 4 credits. Prerequisite: ORIE 3500 or equivalent.

Uses basic concepts and techniques of random processes to construct models for a variety of problems of practical interest. Topics include the Poisson process, Markov chains, renewal theory, models for queuing, and reliability.

**ORIE 3800 Information Systems and Analysis**

Fall. 4 credits.

A systematic and hierarchical approach to the development of information systems, featuring business case justification, requirements analysis, use case analysis, functional analysis, structural design, object-oriented modeling, database design, verification and validation, and project schedule estimation. Graphical tools of analysis (e.g., the Unified Modeling Language) are emphasized. Examples are drawn from business and industrial processes. An integrative design project resulting in a detailed information system design specification (but not necessarily implementation) is required.

**ORIE 4150 Economic Analysis of Engineering Systems**

Spring. 4 credits. Prerequisites: ORIE 3300 and 3150.

Topics include financial planning, including cash-flow analysis and inventory flow models; engineering economic analysis, including discounted cash flows and taxation effects; application of optimization techniques, as in equipment replacement or capacity expansion models, and issues in designing manufacturing systems. Includes a student group project.

**ORIE 4152 Entrepreneurship for Engineers (also MAE/ENGRG 4610)**

Fall. 3 credits. Prerequisite: upper-class engineers or permission of instructor.

For description see MAE 4610.

**ORIE 4154 Revenue Management**

Fall. 3 credits. Prerequisites: ORIE 3300 and 3500, or permission of instructor.

The course covers pricing, capacity control and assortment offering problems. Both static approximations and dynamic programming formulations are emphasized. The optimality of protection-level and bid-price policies in limited settings is illustrated, and these policies are used to find good solutions in more general settings. A structured framework for overbooking decisions is presented. Examples from a variety of industries, such as airline, hospitality, restaurant and broadcasting, are used to illustrate the concepts.

**[ORIE 4300 Optimization Modeling**

Spring. 3 credits. Prerequisite: at least B– in ORIE 3310/5310. Next offered 2009–2010.

Emphasizes modeling complicated decision problems as linear programs, integer programs, or highly structured nonlinear programs. Besides modeling, students are required to assimilate articles from the professional literature and to master relevant software.]

**[ORIE 4320 Nonlinear Optimization**

Fall. 4 credits. Prerequisite: ORIE 3300. Next offered 2010–2011.

Introduction to the practical and theoretical aspects of nonlinear optimization. Gives attention to the computational efficiency of algorithms and the application of nonlinear techniques to linear programming; e.g., interior-point methods. Introduces methods of numerical linear algebra as needed.]

**ORIE 4330 Discrete Models**

Fall. 4 credits. Prerequisites: ORIE 3300 and CS 2110 or permission of instructor.

Covers basic concepts of graphs, networks, and discrete optimization. Fundamental models and applications, and algorithmic techniques for their analysis. Specific optimization models studied include flows in networks, the traveling salesman problem, and network design.

**ORIE 4350 Introduction to Game Theory**

Fall. 4 credits. Prerequisite: ORIE 3300.

Broad survey of the mathematical theory of games, including such topics as two-person matrix and bimatrix games; cooperative and noncooperative n-person games; and games in extensive, normal, and characteristic function form. Economic market games. Applications to weighted voting and cost allocation.

**ORIE 4360 A Mathematical Examination of Fair Representation**

Spring. 3 credits. Prerequisite: MATH 2220 or 2940 or permission of instructor.

Covers the mathematical aspects of the political problem of fair apportionment. The most recognizable form (in the United States) of apportionment is the determination of the number of seats in the U.S. House of Representatives awarded to each state. The constitution indicates that the apportionment should reflect the relative populations, but it does not prescribe a specific method. Indivisibility of seats leads us to interesting mathematical questions and a long, rich, and fractious political history involving many famous figures. The basic ideas extend beyond apportionment of legislatures (in both federal systems and proportional representation systems) to other realms where indivisible resources are to be allocated among competing constituencies.

**[ORIE 4370 Computational Optimization**

Spring. 4 credits. Prerequisite: ORIE 3300. Corequisite: ORIE 3310. Next offered 2010–2011.

Covers computational implementation and related methodology for solving large-scale, real-world integer programming problems. Primary emphasis is on branch-and-cut technology: pre-processing, cut strength, exact and heuristic separation techniques, branching strategies, multi-processing. Hands-on experience with state-of-the-art software for various discrete optimization models, including the traveling salesman, capacitated vehicle routing, and air crew scheduling models; experimentation with massively parallel computational implementation on the IBM BlueGene computer for the largest feasible subsystem problem.]

**[ORIE 4520 Introductory Engineering Stochastic Processes II**

Spring. 4 credits. Prerequisite: ORIE 3510 or equivalent. Next offered 2009–2010.

Topics include stationary processes, martingales, random walks, and gambler's ruin problems, processes with stationary independent increments, Brownian motion and other cases, branching processes, renewal and Markov-renewal processes, reliability theory, Markov decision processes, optimal stopping, statistical inference from stochastic models, and stochastic comparison methods for probability models. Applications to population growth, spread of epidemics, and other models.]

**[ORIE 4540 Extreme Value Analysis with Applications to Finance and Data Communications**

Spring. 3 credits. Prerequisites: undergraduate and M.Eng. students; stochastic processes course at level of ORIE 3510; statistics course. Next offered 2009–2010.

Covers the basic models of extreme events used in hydrology, finance, insurance, environmental science (pollution controls), reliability, risk management. The course material intersects the related field of heavy tailed modeling and the implications of heavy tails in insurance and data networks.]

**ORIE 4580 Simulation Modeling and Analysis**

Fall. 4 credits. Prerequisite: ORIE 3500 (may be taken concurrently) and computing experience.

Introduction to Monte Carlo simulation and discrete-event simulation. Emphasizes tools and techniques needed in practice. Random variate, vector, and process generation modeling using a discrete-event simulation language, input and output analysis, modeling.

**ORIE 4600 Introduction to Financial Engineering**

Fall. 3 credits. Prerequisites: ORIE 3500 and 3510.

This is an introduction to the most important notions and ideas in modern financial engineering, such as arbitrage, pricing, derivatives, options, interest rate models, risk measures, equivalent martingale measures, complete and incomplete markets, etc. Most of the time the course deals with discrete time models. This course can serve as a preparation for a course on continuous time financial models such as ORIE 5600.

**[ORIE 4630 Operations Research Tools for Financial Engineering**

Spring. 3 credits. Prerequisites: engineering math through MATH 2940 and ENGRD 2700 and ORIE 3500. No previous knowledge of finance required. Next offered 2009–2010.

Introduction to the applications of OR techniques, e.g., probability, statistics, and optimization, to finance and financial engineering. First reviews probability and statistics and then surveys assets returns, ARIMA time series models, portfolio selection, regression, CAPM, option pricing, GARCH models, fixed-income securities, resampling techniques, and behavioral finance. Also covers the use of MATLAB, MINITAB, and SAS for computation.]

**[ORIE 4710 Applied Linear Statistical Models**

Spring. Weeks 1–7. 2 credits. Prerequisite: ENGRD 2700. Next offered 2010–2011.

Topics include multiple linear regression, diagnostics, model selection, inference, one and two factor analysis of variance. Theory and applications both treated. Use of MINITAB stressed.]

**[ORIE 4711 Experimental Design**

Spring, weeks 8–14 (alternates with 4712). 2 credits. Prerequisite: ORIE 4710. Next offered 2010–2011.

Covers randomization, blocking, sample size determination, factorial designs, 2^p full and fractional factorials, response surfaces, Latin squares, split plots, and Taguchi designs. Engineering applications. Computing in MINITAB or SAS.]

**[ORIE 4712 Regression**

Spring, weeks 8–14 (alternates with 4711). 2 credits. Prerequisite: ORIE 4710. Next offered 2009–2010.

Covers nonlinear regression, advanced diagnostics for multiple linear regression, collinearity, ridge regression, logistic regression, nonparametric estimation including spline and kernel methods, and regression with correlated errors. Computing in MINITAB or SAS.]

**ORIE 4740 Statistical Data Mining I**

Fall. 4 credits. Prerequisites: ORIE 3500 and MATH 2940 or equivalent; or permission of instructor.

Examines the statistical aspects of data mining, the effective analysis of large data sets. The first half of the course covers the process of building and interpreting statistical models in a variety of settings including multiple regression and logistic regression. The second half connects these ideas to techniques being developed to handle the large data sets that are now routinely encountered in scientific and business applications. Assignments are done using one or more statistical computing packages.

**ORIE 4800 Information Technology**

Spring. 4 credits. Pre- or corequisites: CS/ENGRD 2110, plus either ORIE 3800 or 3120.

This course covers a variety of fundamental aspects of information technology. Topics may include: information transmission, storage, encryption and security; the value of information and the economics of information goods; databases, the Internet, World Wide Web, wireless and cellular networks, and peer-to-peer networks.

**[ORIE 4810 Delivering OR Solutions with Information Technology**

Spring. 3 credits. Prerequisite: ORIE 4800. Next offered 2009–2010.

Study of ways information technology is used to deliver operations research methodology in real applications, including decision support systems, embedded operations research techniques, packaged software, and web-based techniques. Several actual applications are investigated. Labs introduce Visual Basic for Applications (VBA) for decision support.]

**ORIE 4820 Spreadsheet-Based Modeling and Data Analysis**

Spring. 3 credits. Prerequisites: ENGRD 2700, ORIE 3300 or equivalent.

Students develop and implement practical spreadsheet models to analyze data and evaluate decision problems in a hands-on learning environment. Microsoft Excel is heavily used. A wide variety of application areas are covered that incorporate concepts from probability, statistics, and constrained optimization.

**[ORIE 4850 Applications of Operations Research and Game Theory to Information Technology**

Spring. 3 credits. Prerequisites: ORIE 3310, 3510, or permission of instructor. Next offered 2009–2010. Covers a variety of operations research and game theoretic problems arising in information technology. Examples include web searching, network routing and congestion control, online auctions, and trust and reputations in electronic interactions.]

**ORIE 4990 Teaching in ORIE**

Fall, spring. Variable credit. Prerequisite: permission of instructor.

Involves working as a TA in an ORIE course. The instructor assigns credits (the guideline is 1 credit per four hours per week of work with a limit of 3 credits).

**ORIE 4999 ORIE Project**

Fall, spring. Variable credit. Prerequisite: permission of instructor.

Project-type work, under faculty supervision, on a real problem existing in some firm or institution. Opportunities in the course may be discussed with the associate director.

**ORIE 5100 Design of Manufacturing Systems**

Fall. 4 credits. Prerequisite: ORIE seniors and graduate students in engineering and business school; permission of instructor.

Project course in which students, working in teams, design a manufacturing logistics system and conduct capacity, material flow, and cost analysis of their design. Meetings between project teams and faculty advisors are substituted for some lectures. Analytical methods for controlling inventories, planning production, and evaluating system performance are presented in lectures.

**ORIE 5110 Case Studies**

Fall. 1 credit. Prerequisite: M.Eng. students in ORIE.

Presents students with an unstructured problem that resembles a real-world situation. Students work in project groups to formulate mathematical models, perform computer analyses of the data and models, and present oral and written reports.

**[ORIE 5120 Production Planning and Scheduling Theory and Practice**

Fall. 4 credits. Corequisites: ORIE 3300, 3500. Next offered 2009–2010.

Topics include production planning, including MRP, linear programming, and related concepts. Scheduling and sequencing work in manufacturing systems. Job release strategies and control of work in process inventories. Focus is on setup time as a determinant of plans and schedules.]

**ORIE 5122 Inventory Management**

Fall. 3 credits. Prerequisite: ORIE 3310, 3510, or permission of instructor.

The first portion of this course is devoted to the analysis of several deterministic and probabilistic models for the control of single and multiple items at one of many locations. The second portion is presented in an experiential learning format. The focus is on analyzing and designing an integrated production and distribution system for a global company. Applications are stressed throughout.

**ORIE 5126 Supply Chain Management**

Spring. 3 credits. Prerequisites: one of the following: ORIE 3120, 4100, or 5122.

A supply chain is the scope of activities that convert raw materials (e.g., wheat) to finished products delivered to the end consumer (e.g., a box of cereal at the local P&C), usually spanning several corporations. Supply chain management focuses on the flow of products, information, and money through the supply chain. An overview of issues, opportunities, tools, and approaches. Emphasis is on business processes, system dynamics, control, design, re-engineering. Covers the relationship between the supply chain and the company's strategic position relative to its clients and its competition. Considers dimensions of inter-corporate relationships with partners, including decision-making, incentives, and risk.

**ORIE 5130 Service System Modeling and Design**

Spring. 3 credits. Corequisites: ORIE 3310, 3510; ability to program simple algorithms in some appropriate environment (e.g., VisualBasic or MATLAB).

Today's economy is dominated by service industries. These systems differ from manufacturing industries in many ways, but primarily in the level of interaction with the customer. Examples of service systems include contact centers (aka call centers), airlines, and hospitals. This course covers various techniques that are useful in the analysis and design of such systems. It is structured around a number of cases that drive the need for the theory. The emphasis is on modeling and solving the models. Both operational and strategic decisions are covered through appropriate examples.

**ORIE 5140 Applied Systems Engineering (also CEE/CIS 5040, ECE 5120, MAE 5910)**

Fall. 3 credits. Prerequisite: permission of instructor.

For description, see SYSEN 5100.

**ORIE 5142 Systems Analysis Architecture, Behavior, and Optimization (also CEE/CIS 5050, ECE 5130, MAE 5920)**

Spring. 3 credits. Prerequisite: CEE/CIS 5040, ECE 5120, ORIE 5140, or MAE 5910.

For description, see SYSEN 5200.

**ORIE 5150 Economic Analysis of Engineering Systems**

Spring. 4 credits. Prerequisites: ORIE 3300 and 3150. Lectures concurrent with ORIE 4150.

For description, see ORIE 4150.

**ORIE 5190–5191 Selected Topics in Applied Operations Research**

Fall, spring. Variable credit. Prerequisite: permission of instructor.

Current topics dealing with applications of operations research.

**ORIE 5300 Operations Research I: Optimization I**

For description, see ORIE 3300.

**ORIE 5310 Optimization II**

For description, see ORIE 3310.

**ORIE 5311 Operations Research I: Topics in Linear Optimization**

Spring. 1 credit. Pre- or corequisite: M.Eng. students in ORIE; ORIE 5300. Not open to students who have already taken ORIE 3310 or 5310.

Extension of ORIE 5300 that deals with applications and methodologies of dynamic programming, integer programming, and large-scale linear programming.

**[ORIE 5340 Heuristic Methods for Optimization (also CEE 5090, CIS 5720)**

Fall. 3 or 4 credits. Prerequisite: graduate standing or CS/ENGRD 2110, 3510 or CEE/ENGRD 3200 or permission of instructors.

For description, see CEE 5090.]

**ORIE 5500 Engineering Probability and Statistics II**

For description, see ORIE 3500.

**ORIE 5510 Operations Research II: Introduction to Stochastic Processes I**

For description, see ORIE 3510.

**[ORIE 5520 Introductory Engineering Stochastic Processes II**

Spring. 4 credits. Prerequisite: ORIE 3510 or equivalent.

Lectures concurrent with ORIE 4520. For description, see ORIE 4520.]

**[ORIE 5540 Extreme Value Analysis with Applications to Finance and Data Communications**

Spring. 3 credits.

For description, see ORIE 4540.]

**ORIE 5550 Applied Time-Series Analysis**

Fall. 3 credits. Prerequisites: ORIE 3510 and ENGRD 2700 or permission of instructor.

The first part of this course treats regression methods to model seasonal and nonseasonal data. After that, Box-Jenkins models, which are versatile, widely used, and applicable to nonstationary and seasonal time series, are covered in detail. The various stages of model identification, estimation, diagnostic checking, and forecasting are treated. Analysis of real data is carried out. Assignments require computer work with a time-series package.

**[ORIE 5560 Queueing Systems: Theory and Applications**

Fall. 3 credits. Prerequisite: ORIE 3510 or permission of instructor. Next offered 2009–2010.

Covers basic queueing models; delay and loss systems; finite source, finite capacity, balking, reneging; systems in series and in parallel; FCFS versus LCFS; busy period problems; output; design and control problems; priority systems; queueing networks; the product formula; time sharing; server vacations; and applications to equipment maintenance, computer operations and flexible manufacturing systems.]

**ORIE 5580 Simulation Modeling and Analysis**

Fall. 4 credits. Prerequisite: ORIE 3500 (may be taken concurrently) and computing experience.

Lectures concurrent with ORIE 4580. For description, see ORIE 4580.

**ORIE 5581 Monte Carlo Simulation**

Fall, weeks 1–7. 2 credits. Co-meets with ORIE 4580.

Introduction to Monte Carlo simulation. Emphasis on tools and techniques needed in practice. Random variate, vector and process generation, input and output analysis, modeling.

**ORIE 5582 Monte Carlo Methods in Financial Engineering**

Spring, weeks 8–14. 2 credits. Prerequisite: ORIE 4580.

An overview of Monte Carlo methods as they apply in financial engineering. Generating sample paths. Variance reduction (including quasi random number), discretization, and sensitivities. Applications to derivative pricing and risk management.

**ORIE 5600 Financial Engineering with Stochastic Calculus I**

Fall. 4 credits. Prerequisite: knowledge of probability at level of ORIE 3500.

Introduction to continuous-time models of financial engineering and the mathematical tools required to use them, starting with the Black-Scholes model. Driven by the problem of derivative security pricing and hedging in this model, the course develops a practical knowledge of stochastic calculus from an elementary standpoint, covering topics including Brownian motion, martingales, the Ito formula, the Feynman-Kac formula, and Girsanov transformations.

**ORIE 5610 Financial Engineering with Stochastic Calculus II**

Spring. 4 credits. Prerequisite: ORIE 5600.

Building on the foundation established in ORIE 5600, this course presents no-arbitrage theories of complete markets, including models for equities, foreign exchange, and fixed-income securities, in relation to the main problems of financial engineering: pricing and hedging of derivative securities, portfolio optimization, and risk management. Other topics include model calibration and incomplete markets.

**ORIE 5620 Credit Risk: Modeling, Valuation, and Management**

Fall. 4 credits. Prerequisite: ORIE 3510.

Credit risk refers to losses due to changes in the credit quality of a counter party in a financial contract. This course is an introduction to the modeling and valuation of credit risks. Emphasis is on credit derivative instruments used for hedging credit risks, including credit swaps, spread options, and collateralized debt obligations.

**ORIE 5630 Computational Methods in Finance**

Fall. 3 credits. Prerequisite: ORIE M.Eng. students.

This course covers computational techniques such as binomial trees, solution of PDEs, and Monte Carlo simulation for pricing financial instruments such as European and American options, path-dependent options, and bonds. Other computational topics such as delta and gamma hedging, Value at Risk, and portfolio problems will also be covered. The emphasis will be on implementation.

**ORIE 5640 Statistics for Financial Engineering**

Spring. 4 credits. Prerequisites: ORIE 3500/5500 and at least one of ORIE 4600, 4630, or 4740.

Regression, ARIMA, GARCH, stochastic volatility, and factor models. Calibration of financial engineering models. Estimation of diffusion models. Estimation of risk measures. Multivariate models and copulas. Bayesian statistics. Students will be instructed in the use of R software; prior knowledge of R is helpful but not required. This course is intended for M.Eng. students in financial engineering and assumes some familiarity with finance and financial engineering. Students not in the financial engineering program are welcome if they have a suitable background. Students with no background in finance should consider taking ORIE 4630 instead.

**ORIE 5650 Quantitative Methods of Financial Risk Management**

Spring. 3 credits. Prerequisite: ORIE 3500.

A historical perspective of market risk measurement including the Markowitz, CAPM and APT models, a description of the value-at-risk approach and an overview of VaR variants and extensions such as delta-VaR, CVaR etc. The course will survey other methods for evaluating risk and consider multivariate methods for evaluating portfolios requiring copula tools which have become popular. Topics in credit risk: methods for determining default probabilities and company ratings based on financial ratios (logit, probit and discriminant analysis, decision trees, etc.), and approaches to measuring credit risk which can be roughly divided into structural models and reduced-form models.

**ORIE 5660 Bond Mathematics and Mortgage-Backed Securities**

Fall. 3 credits. Prerequisites: Limited to Financial Engineering M.Eng. students in Manhattan.

A transaction-oriented course covering U.S. Bond markets. The course covers valuation, trading strategies, and risk profiles of bonds, with a special emphasis on mortgage-backed securities.

**[ORIE 5770 Quality Control**

Fall. 3 credits. Prerequisite: ENGRD 2700. Next offered 2009–2010.

Covers concepts and methods for process and acceptance control; control charts for variables and attributes; process capability analysis; acceptance sampling; continuous sampling plans; life tests; and use of experimental design and Taguchi methods for off-line control.]

**ORIE 5910 Master of Engineering Manufacturing Project**

Fall, R grade only; spring, 5 credits. Prerequisite: M.Eng. students enrolled in manufacturing option.

Project course coordinated by Center for Manufacturing Enterprise.

**ORIE 5912 Special Topics in Financial Engineering**

Fall. 1–8 credits. Prerequisites: Limited to Financial Engineering M.Eng. students in Manhattan.

Module-based course focusing on topics relevant to current financial markets. Practitioner-led segments will cover a wide range of quantitative and qualitative topics in the securities industry.

**ORIE 5940 Systems Engineering Project**

Fall; R grade only; spring, 8 credits. Prerequisite: M.Eng. students enrolled in systems engineering option.

Substantial, group-based design project that has a strong systems design component. The project must be approved by an ASE 1 instructor before the student enrolls in the course. (The following projects are pre-approved: FSAE, HEV, Robocup, Brain.) A formal report is required.

**ORIE 5960 Applied Financial Engineering**

Fall and spring. 5 credits. Prerequisite: ORIE and M. Eng, students concentrating in financial engineering.

Project course satisfying the engineering design project requirement for financial engineering M.Eng. students.

**ORIE 5961 Applied Financial Engineering**

Fall. 5 credits. Prerequisites: Limited to Financial Engineering M.Eng. students in Manhattan.

Project course in Manhattan satisfying the engineering design project requirement for the M.Eng degree.

**ORIE 5980 Project**

Fall, R grade only; spring, 5 credits. Prerequisite: M.Eng. students.

Identification, analysis, design, and evaluation of feasible solutions to some applied problem in the ORIE field. A formal report and oral defense of the approach and solution are required.

**ORIE 6122 Advanced Production and Inventory Planning**

Spring. 3 credits.

Introduction to a variety of production and inventory control planning problems, the development of mathematical models corresponding to these problems, and a study of approaches for finding solutions.

**[ORIE 6127 Computational Issues in Large Scale Data-Driven Models**

Fall. 3 credits. Pre- or corequisites: ORIE 6300, 6500 and 6700. Next offered 2009–2010.

Availability of massive datasets such as web logs and point-of-sale transactions raises new modeling and computational issues. This course provides an introduction to this emerging research area. Topics include data-driven models in operation management, asymptotic statistics, uniform convergence of empirical process, and efficient computational methods. There is discussion of applications in engineering, economics, and marketing, along with current open research problems.]

**ORIE 6140 Mathematical Modeling of Operational Systems**

Fall. 2 credits. Prerequisites: ORIE 6300, 6500, or equivalent.

The art and science of developing, using and explicating mathematical models, presented in a studio/workshop environment. Structuring of a variety of operational "situations" so they can be reasonably represented by a mathematical model. Extensive class discussion and out-of-class investigation of potential mathematical approaches to each situation. Incorporation of data analysis.

**ORIE 6300 Mathematical Programming I**

Fall. 4 credits. Prerequisites: advanced calculus and elementary linear algebra.

Rigorous treatment of the theory and computational techniques of linear programming and its extensions, including formulation, duality theory, algorithms; sensitivity analysis; network flow problems and algorithms; theory of polyhedral convex sets, systems of linear equations and inequalities, Farkas' Lemma; and exploiting special structure in the simplex method and computational implementation.

**[ORIE 6310 Mathematical Programming II**

Spring. 4 credits. Prerequisite: ORIE 6300. Next offered 2009–2010.

Continuation of ORIE 6300. Introduces nonlinear programming, interior-point methods for linear programming, complexity theory, and integer programming. Includes some discussion of dynamic programming and elementary polyhedral theory.]

**[ORIE 6320 Nonlinear Programming**

Spring. 3 credits. Prerequisite: ORIE 6300. Next offered 2009–2010.

Necessary and sufficient conditions for unconstrained and constrained optima. Topics include the duality theory, computational methods for unconstrained problems (e.g., quasi-Newton algorithms), linearly constrained problems (e.g., active set methods), and nonlinearly constrained problems (e.g., successive quadratic programming, penalty, and barrier methods).]

**ORIE 6325 Interior-Point Methods for Mathematical Programming**

Fall. 3 credits. Prerequisites: MATH 4110 and ORIE 6300, or permission of instructor.

Interior-point methods for linear, quadratic, and semidefinite programming and, more generally, for convex programming. Discusses the basic ingredients—barrier functions, central paths, and potential functions—that go into the construction of polynomial-time algorithms and various ways of combining them. Emphasizes recent mathematical theory and the most modern viewpoints.

**[ORIE 6327 Semidefinite Programming**

Spring. 3 credits. Pre- or corequisite: ORIE 6325. Next offered 2010–2011.

Covers linear optimization over the cone of positive semidefinite symmetric matrices; applications to control theory, eigenvalue optimization, and strong relaxations of combinatorial optimization problems; duality; computational methods, particularly interior-point algorithms.]

**ORIE 6328 Convex Analysis**

Spring. 3 credits. Prerequisite: ORIE 6300 or permission of instructor.

Self-contained development of convex analysis and optimization. Convex sets and functions, subgradients, continuity, Fenchel, conic, and Lagrangian duality. Nonsmooth analysis: Clarke and limiting subgradients. Self-concordance and smooth convex optimization. Bundle methods for nonsmooth convex optimization.

**[ORIE 6330 Graph Theory and Network Flows**

Fall. 3 credits. Prerequisite: permission of instructor. Next offered 2010–2011.

Topics include directed and undirected graphs; bipartite graphs; Hamilton cycles and Euler tours; connectedness, matching, and coloring; flows in capacity-constrained networks; and maximum flow and minimum cost flow problems.]

**[ORIE 6334 Combinatorial Optimization**

Fall. 3 credits. Next offered 2009–2010.

Topics in combinatorics, graphs, and networks, including matching, matroids, polyhedral combinatorics, and optimization algorithms.]

**ORIE 6335 Scheduling Theory**

Spring. 3 credits.

Scheduling and sequencing problems, including single-machine problems, parallel-machine scheduling, and shop scheduling. The emphasis is on the design and analysis of polynomial time optimization and approximation algorithms and on related complexity issues.

**[ORIE 6336 Integer Programming**

Fall. 3 credits. Prerequisite: ORIE 6300. Next offered 2009–2010.

Topics include discrete optimization; linear programming in which the variables must assume integral values; theory, algorithms, and applications; and cutting-plane and enumerative methods, with additional topics drawn from recent research in this area.]

**[ORIE 6350 Foundations of Game Theory and Mechanism Design for Engineering Applications**

Fall. 3 credits. Prerequisite: basic knowledge of operations research at level of ORIE 6300 and 6500. No prior knowledge of game theory or computer networks assumed. Next offered 2010–2011.

Provides a rigorous foundation for the applications of game theory and mechanism design to problems in operations research and computer science. The goal is to develop a deep understanding of the fundamental issues that are important in many applications while presenting many current open research problems.]

**ORIE 6500 Applied Stochastic Processes**

Fall. 4 credits. Prerequisite: one-semester calculus-based probability course.

Introduction to stochastic processes that presents the basic theory together with a variety of applications. Topics include Markov processes, renewal theory, random walks, branching processes, Brownian motion, stationary processes, martingales, and point processes.

**ORIE 6510 Probability**

Spring. 4 credits. Prerequisite: real analysis at level of MATH 4130; one-semester calculus-based probability course.

Covers sample spaces, events, sigma fields, probability measures, set induction, independence, random variables, expectation, review of important distributions and transformation techniques, convergence concepts, laws of large numbers and asymptotic normality, and conditioning.

**[ORIE 6540 Advanced Stochastic Processes**

Fall. 3 credits. Prerequisite: ORIE 6510 or equivalent. Next offered 2010–2011.

Topics include Brownian motion, martingales, Markov processes, and topics selected from: diffusions, stationary processes, point processes, weak convergence for stochastic processes and applications to diffusion approximations, Lévy processes, regenerative phenomena, random walks, and stochastic integrals.]

**[ORIE 6570 Queues and Control of Queues: The Dynamic Programming Approach**

Fall. 3 credits. Next offered 2010–2011.

We will cover basic queueing theory followed by an introduction to Markov decision processes (MDPs). The second part of the class will cover the use of MDPs to develop control policies in a variety of queueing settings.]

**[ORIE 6580 Simulation**

Spring. 3 credits. Prerequisite: computing experience and ORIE 6500 or equivalent, or permission of instructor. Next offered 2010–2011.

Introduction to Monte Carlo and discrete-event simulation. Emphasizes underlying theory. Random variate generation, input and output analysis, variance reduction, selection of current research topics.]

**ORIE 6600 Mathematical Finance I**

Spring. 3 credits. Prerequisite: ORIE 6500.

Introduction to mathematical finance in discrete time for Ph.D. students. The course covers arbitrage theory, pricing and hedging of derivative securities. American contingent claims, investor preferences and corresponding optimization problems, risk measures, and imperfect hedging strategies.

**ORIE 6610 Mathematical Finance II**

Fall. 3 credits. Prerequisites: ORIE 6500, ORIE 6510, and ORIE 6600.

Introduction to stochastic calculus, stochastic differential equations, and applications to continuous-time finance such as the Black-Scholes formula, local and stochastic volatility models, and term structure models for interest rates of volatilities. Corresponding mathematical foundations such as martingale theory, Itô integration, and Girsanov's theorem are also provided.

**[ORIE 6630 Empirical and Computational Issues in Finance**

Spring. 3 credits. Prerequisites: stochastic processes course at level of ORIE 6500; statistics course at level of ORIE 6700, or permission of instructor. Next offered 2009–2010.

Designed to introduce students to existing empirical work in finance and to demonstrate the use of statistical, econometric, and numerical methods in the analysis of financial data. Topics include linear and nonlinear time series analysis, high-frequency data and market microstructure, continuous-time models, extreme values and quantile estimation, volatility models, and MCMC methods. Numerous applications using market data are presented. MATLAB programming skills are useful.]

**ORIE 6700 Statistical Principles**

Fall. 4 credits. Corequisite: ORIE 6500 or equivalent.

Topics include review of distribution theory of special interest in statistics: normal, chi-square, binomial, Poisson, t, and F; introduction to statistical decision theory; sufficient statistics; theory of minimum variance unbiased point estimation; maximum likelihood and Bayes estimation; basic principles of hypothesis testing, including Neyman-Pearson Lemma and likelihood ratio principle; confidence interval construction; and introduction to linear models.

**ORIE 6710 Intermediate Applied Statistics**

Spring. 3 credits. Prerequisite: ORIE 6700 or equivalent.

Topics include statistical inference based on the general linear model; least-squares estimators and their optimality properties; likelihood ratio tests and corresponding confidence regions; and simultaneous inference. Applications in regression analysis and ANOVA models. Covers variance components and mixed models. Use of the computer as a tool for statistics is stressed.

**[ORIE 6720 Sequential Methods in Statistics**

Spring. 3 credits. S–U grades only. Next offered 2010–2011.

The statistical theory of sequential design and analysis of experiments has many applications; including monitoring data from clinical trials in medical studies and quality control in manufacturing operations. This course covers classical sequential hypothesis tests, Wald's SPRT, stopping rules, Kiefer-Weiss test, optimality, group sequential methods, estimation, repeated confidence intervals, stochastic curtailment, adaptive designs, and Bayesian and decision theoretic approaches.]

**[ORIE 6740 Statistical Learning Theory for Data Mining**

Fall. 3 credits. Prerequisites: probability course at level of ORIE 6510; statistics course at level of ORIE 6700. Next offered 2010–2011.

Provides a thorough grounding in probabilistic and computational methods for statistical data mining. Covers a subset of the following topics from supervised and unsupervised data mining: the framework of learning. Performance measures and model selection. Methodology, theoretical properties and computing algorithms used in parametric and nonparametric methods for regression and classification. Frequentist and Bayesian methods.]

**[ORIE 6780 Bayesian Statistics and Data Analysis**

Spring. 3 credits. Prerequisites: ORIE 6700 or an equivalent course in mathematical statistics. Next offered 2009–2010.

Priors, posteriors, Bayes estimators, Bayes factors, credible regions, hierarchical models, computational methods (especially MCMC), empirical Bayes methods, Bayesian robustness. Includes data analysis and MCMC computation using R and WinBUGS.]

**ORIE 7190–7191 Selected Topics in Applied Operations Research**

Fall, spring. Credit TBA.

Current research topics dealing with applications of operations research.

**ORIE 7390–7391 Selected Topics in Mathematical Programming**

Fall, spring. Credit TBA.

Current research topics in mathematical programming.

**ORIE 7590–7591 Selected Topics in Applied Probability**

Fall, spring. Credit TBA.

Topics are chosen from current literature and research areas of the staff.

**ORIE 7790–7791 Selected Topics in Applied Statistics**

Fall, spring. Credit TBA.

Topics are chosen from current literature and research of the staff.

**ORIE 7900 Special Investigations**

Fall, spring. Credit TBA.

For individuals or small groups. Study of special topics or problems.

**ORIE 9000 Operations Research Graduate Colloquium**

Fall, spring. 1 credit.

Weekly one and one-half hour meeting devoted to presentations by distinguished visitors, by faculty members, and by advanced graduate students on topics of current research in the field of operations research.

**ORIE 9100–9101 Enterprise Engineering Colloquium (also MAE 5940)**

9100, fall; 9101, spring. 1 credit each semester. S–U grades.

Weekly meeting for master of engineering students. Discussion with industry speakers and faculty members on the uses of engineering in the economic design, manufacturing, marketing, and distribution and goods and services.

**ORIE 9110 M.Eng. Professional Review**

Fall. 1 credit. Limited to ORIE M.Eng. students in their second or third semester. S-U grades only.

An interactive course in which students present findings and share lessons from their summer internship experiences.

**ORIE 9160 Seminar in Financial Engineering**
Fall. 1 credit. Prerequisites: Limited to Financial Engineering M.Eng. students in Manhattan.
Weekly roundtable meeting for students concentrating in financial engineering. Current market events, practices, and research will be discussed with faculty and financial industry partners.

**ORIE 9999 Thesis Research**
Fall, spring. Credit TBA.
For individuals doing thesis research for master's or doctoral degrees.

# SYSTEMS ENGINEERING

P. L. Jackson, director; A. R. George, assoc. director; L. K. Nozick, director of graduate studies; M. Campbell, R. D'Andrea, A. Davidson, E. Garcia, H. O. Gao, A. S. Lewis, J. A. Muckstadt, A. F. Myers, M. Peck, R. O. Roundy, F. B. Schneider, B. Selman, C. A. Shoemaker, J. R. Stedinger, R. J. Thomas, H. Topaloglu, M. A. Turnquist, F. J. Wayno, Jr.

**SYSEN 1100 Getting Design Right: A Systems Approach**
Summer six-week session. 2 credits. Web-delivered. Instructor: Peter L. Jackson.
This course is a freshman-level exposure to the product design process. The process of getting design right is sometimes called systems engineering. We explain the process using the acronym DMEODVI (Define, Measure, Explore, Optimize, Design, Verify, and Iterate). The process begins with understanding customer requirements and ends with validating the design against those requirements. It can then be iterated to greater levels of design detail. The focus is not on detailed engineering design but rather on the process of ensuring that the detailed design will meet the needs of the customer. Students work through the steps of the process with reference to a particular product design challenge. The course is web-delivered using the Blackboard learning instruction system. Pre-requisites: high school mathematics and science, and familiarity with spreadsheet modeling (e.g., MS Excel).

**SYSEN 5100 Applied Systems Engineering (also CEE/CS 5040, ECE/ORIE 5120, MAE 5910)**
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in group-based project with strong system design component approved by course instructor. M. Peck, A. R. George, and P. Jackson.
Fundamental ideas of systems engineering, and their application to design and development of various types of engineered systems. Defining system requirements, creating effective project teams, mathematical tools for system analysis and control, testing and evaluation, economic considerations, and the system life cycle. Students majoring in Systems Engineering enroll in SYSEN 5100. Students taking the minor in Systems Engineering enroll in CEE/CIS 5040, ECE/ORIE 5120, or MAE 5910. Students in distance-learning programs enroll in SYSEN 5110. Course is identical for all versions.

**SYSEN 5110 Applied Systems Engineering**
Fall. 3 credits. Intended for off-campus students. Prerequisites: senior or graduate standing in engineering field; concurrent or recent (past two years) enrollment in group-based project with strong system design component approved by course instructor. Staff.
For description, see SYSEN 5100.

**SYSEN 5200 Systems Architecture, Behavior, and Optimization (also MAE 5920, CEE/CIS 5050, ECE 5130, ORIE 5142)**
Spring. 3 credits. Prerequisite: Applied System Engineering MAE 5910, CEE/CIS 5040, ECE/ORIE 5120, SYSEN 5100 or 5110, or permission of instructor. H. Topaloglu.
This is an advanced course in the application of the systems engineering process to the architecture design and operation of complex systems. Topics include techniques for design, simulation, optimization, and control of complex systems. Case studies and system simulations in diverse areas provide context for the application of these techniques.

Students majoring in Systems Engineering enroll in SYSEN 5200. Students taking the minor in Systems Engineering enroll in MAE 5920, CEE 5252, CIS 5050, ECE 5130, or ORIE 5142. Students in Continuing Education enroll in SYSEN 5210. Course is identical for all versions.

**SYSEN 5210 Systems Architecture, Behavior, and Optimization**
Spring. 3 credits. Intended for off-campus students. Prerequisites: Applied Systems Engineering or permission of instructor. Staff.
For description, see SYSEN 5200.

**SYSEN 5300 Systems Engineering for the Design and Operation of Reliable Systems (also MAE 5930)**
Fall. 3–4 credits. Prerequisites: SYSEN 5100 and either ENGRD 2700 or CEE 3040 or permission of instructors. H. O. Gao.
Develops skills in the design, operation and control of systems for reliable performance. Focuses on four key themes; risk analysis (with a particular emphasis on risk assessment and risk characterization), modeling system reliability (including the development of statistical models based on accelerated life testing), quality control techniques and the optimization of system design for reliability. Students in distance-learning programs enroll in SYSEN 5310. Lectures are identical for all versions.

**SYSEN 5310 Systems Engineering For the Design and Operation of Reliable Systems**
Fall. 3–4 credits. Prerequisites: SYSEN 5100 and either ENGRD 2700 or CEE 3040 or permission of instructor. H. O. Gao.
Intended for off-campus students. For description, see SYSEN 5300.

**SYSEN 5700 Special Topics in Systems Engineering**
On demand. 1–4 credits. Staff.
Supervised study by individuals or small groups of one or more specialized topics not covered in regular courses.

**SYSEN 5710 Practicum in Systems Engineering**
On demand. 1–4 credits. Staff.
Supervised study by individuals or small groups of one or more specialized topics not covered in regular courses.

**SYSEN 5900 Systems Engineering Design Project**
1–8 credits. Prerequisite: permission of instructor. Staff.
A design project that incorporates the principles of systems engineering for a complex system. Projects are performed by teams of students working together to meet the requirements of the project.

**SYSEN 5920 Systems Engineering Management for Virtual Teams**
Summer. 1 credit. Prerequisites: matriculation in Systems Engineering Master of Engineering distance learning degree program. P. L. Jackson and F. J. Wayno.
First of two one-week intensive experiential courses (35 hours) in systems engineering management, with emphasis on laying the social groundwork for students to conduct projects in geographically dispersed teams. Course involves a significant design challenge that must be completed within the week. A leadership laboratory is run simultaneously with the design experience to encourage students to self-assess their leadership style and practices in systems engineering projects.

**SYSEN 5940 Creativity and Innovation Within Systems Engineering**
Summer 2009. 1 credit. Prerequisites: matriculation in M.Eng. (Systems Engineering) distance learning degree program; CEE 6910 (Principles of Project Leadership); SYSEN 5920. P. L. Jackson and F. J. Wayno.
Second of two one-week intensive courses (35 hours) in systems engineering management with emphasis on understanding individual creativity and organizational innovation and on developing the required systems engineering leadership skills to foster both.

**SYSEN 5960 Systems Engineering Design Project for Virtual Teams**
Fall, spring, summer. Variable credit. Prerequisites: matriculation in Systems Engineering M.Eng. distance learning degree program; SYSEN 5100, SYSEN 5920, SYSEN 5940, and SYSEN 6910, or permission of instructor. Staff.
Systems engineering project for geographically dispersed teams. Fulfills M.Eng. degree requirement for project, subject to credit hour minimum.

**SYSEN 6800 Topics in Systems Engineering Research**
Spring. 1.5 credits. Staff.
Advanced topics in systems engineering research.

# THEORETICAL AND APPLIED MECHANICS

T. J. Healey, chair; J. A. Burns, K. B. Cady, J. M. Guckenheimer, C. Y. Hui, J. T. Jenkins, S. Mukherjee, S. L. Phoenix, R. H. Rand, A. L. Ruina, W. H. Sachse, S. Strogatz, Z. J. Wang, A. Zehnder. Emeritus: E. Cranch, R. H. Lance.

## Basics in Engineering Mathematics and Mechanics

**[TAM 1180 Design Integration: DVDs and iPods (also ENGRI 1180)**

Spring. 3 credits. Next offered 2009–2010.

Course in Introduction to Engineering series. For description, see ENGRI 1180.]

**TAM 2020 Mechanics of Solids (also ENGRD 2020)**

Fall, spring. 4 credits Prerequisite: PHYS 1112, co-registration in MATH 1920, or permission of instructor.

For description, see ENGRD 2020.

**TAM 2030 Dynamics (also ENGRD 2030)**

Fall, spring. 3 credits. Prerequisite: TAM 2020, co-registration in MATH 2930, or permission of instructor.

For description, see ENGRD 2030.

## Engineering Mathematics

**TAM 3100 Introduction to Applied Mathematics I**

Fall, spring. 3 credits. Prerequisites: MATH 2930 and 2940.

Covers initial value, boundary value, and eigenvalue problems in linear ordinary differential equations. Also covers special functions, linear partial differential equations. This is an introduction to probability and statistics. Use of computers to solve problems is emphasized.

**[TAM 3110 Introduction to Applied Mathematics II**

Spring. 3 credits. Prerequisite: MATH 2940 or equivalent (TAM 3110 can be taken independently of TAM 3100). Next offered 2009–2010.

Introduction to complex variable theory, including Cauchys integral theorem, Method of Residues, conformal mapping. Applications to inversion of transforms.]

**[TAM 3120/5120 Introduction to Mathematical Modeling**

Spring. 3 credits. Prerequisite: MATH 2940 or equivalent (TAM 3110 can be taken independently of 3100). Next offered 2009–2010.

Mathematical modeling of physical and biological systems.]

**TAM 6100 Methods of Applied Mathematics I**

Fall. 3 credits. Intended for beginning graduate students in engineering and science. Intensive course requiring more time than normally available to undergraduates (see TAM 3100–3110) but open to exceptional undergraduates by permission of instructor.

Emphasis is on applications. Course covers linear algebra, calculus of several variables, vector analysis, series, ordinary differential equations, and complex variables.

**TAM 6110 Methods of Applied Mathematics II**

Spring. 3 credits. Prerequisite: TAM 6100 or equivalent.

Emphasis is on applications. Course covers partial differential equations, transform techniques, tensor analysis, and calculus of variations.

**[TAM 6120 Methods of Applied Mathematics III**

Spring. 3 credits. Prerequisite: TAM 6100 and 6110 or equivalent. Next offered 2009–2010.

Topics include: integral transform, methods, Wiener-Hopf technique, solutions of integral equations and partial differential equations.]

**TAM 6130 Asymptotics and Perturbation Methods**

Spring. 3 credits. Prerequisites: TAM 6100 and 6110 or equivalent.

Topics include asymptotic behavior of solutions of linear and nonlinear ODE (e.g., the WKB boundary layer and multiple-scale methods) and symptotic expansion of integrals (method of steepest descent, stationary phase, and Laplace methods). Also covers regular and singular perturbation methods for PDE (e.g., method of composite expansions). Other topics (depending on instructor) may include normal forms, center manifolds, Liapunov-Schmidt reductors, and Stokes phenomenon. The course may also include computer exercises at the option of the instructor.

**TAM 6170 Advanced Mathematical Modeling—Biological and Fluid Dynamics**

Spring. 3 credits.

Covers the fundamentals of fluid dynamics that rises in biological fluid dynamics such as the motion of the microscope cells in low Reynolds number flows and unsteady aerodynamics of flapping flight and free falling objects. The topics in fluid dynamics include Stokes flow, propulsion of a beating flagellum and swimming sheets, potential flow, unsteady airfoil theory, reduced model of unsteady forces on a fluttering and tumbling object, and computational methods. The current research in biofluids will be discussed in some depth.

**[TAM 7180 Topics in Applied Mathematics**

Spring. 3 credits. Next offered 2009–2010.]

## Continuum Mechanics

**TAM 4550 Introduction to Composite Materials (also CEE 4770, MAE 4550, MSE 5550)**

Fall. 3 credits. Prerequisite: ENGRD 2020.

Topics include introduction to composite materials; varieties and properties of fiber reinforcements and matrix materials; micromechanics of stiffness and stress transfer in discontinuous fiber/matrix arrays; orthotropic elasticity as applied to parallel fibers in a matrix and lamina; theory of stiffness (tension, bending, torsion) and failure of laminates and composite plates, including computer software for design; and manufacturing methods and applications for composites. There is a group component design and manufacturing paper required, and a group laboratory on laminated component fabrication.

**TAM 5910 Master of Engineering Design Project I**

Fall. 3–12 credits, variable.

M.Eng. (mechanics) project related to the master of engineering in mechanics.

**TAM 5920 Master of Engineering Design Project I**

Spring. 3–12 credits, variable.

M.Eng. (mechanics) project related to the master of engineering in mechanics.

**TAM 6550 Advanced Composite Materials (also CEE 6760, MAE/MSE 6550)**

Spring. 4 credits. TAM 4550/5550 not a prerequisite but excellent background.

Topics center around micromechanical and statistical (reliability) aspects of the strength and fatigue of fibrous composites. Topics include Hedgepeth shear-lag models of stress transfer around arrays of fiber breaks; statistical theories of composite failure to forecast reliability; stress distributions around holes and cuts in composite laminates; and compressive strength of composites.

**TAM 6630 Solid Mechanics I**

Fall. 4 credits.

Rigorous introduction to solid mechanics emphasizing linear elasticity: tensors; deformations, rotations and strains; balance principles; stress; small-strain theory; linear elasticity, anisotropic and isotropic; basic theorems of elastostatics; and boundary-value problems, e.g., plates, St. Venant's solutions.

**TAM 6640 Solid Mechanics II**

Spring. 4 credits. Prerequisites: MATH 6110 and TAM 6630 or equivalent.

Preparation for advanced courses in solid mechanics. Topics include singular solutions in linear elasticity; plane stress, plane strain, anti-plane shear, airy stress functions; linear viscoelasticity; cracks and dislocations; classical plasticity; thermoelasticity; and three-dimensional elasticity.

**TAM 7510 Continuum Mechanics and Thermodynamics**

Spring. 3 credits. Prerequisites: TAM 6100 and 6110; and 6630 and 6640 or equivalents.

Course topics include kinematics; conservation laws; the entropy inequality; constitutive relations: frame indifference, material symmetry; and finite elasticity, rate-dependent materials, and materials with internal state variables.

**[TAM 7520 Nonlinear Elasticity**

Spring. 3 credits. Prerequisites: TAM 6100, 6110, and 7510 or equivalents. Next offered 2009–2010.

Review of governing equations. Topics include linearization and stability; constitutive inequalities; exact solution of special problems.]

**[TAM 7530 Fracture**

Spring. 3 credits. Prerequisites: TAM 6100 or 6110; and 6630 and 6640 or equivalents. Next offered 2009–2010.

Also covers nonlinear rate-independent, small-scale deformation fracture mechanics: plastic fracture, J-integrals.]

**[TAM 7540 Topics in Continuum Mechanics]**

**TAM 7570 Inelasticity**

Spring. 3 credits.

Plasticity: dislocations and slip systems; early experimental observations; torsion and bending of bars; inflation of thick cylinders and spheres; general equations governing yielding, flow and work hardening; solution of general boundary value problems; numerical solutions radial return and the consistent tangent operator. Linear viscoelasticity: simple rheological models; correspondence principle; hereditary integral approach; torsion and bending of bars; inflation of thick cylinders and spheres; solution of general quasi-static boundary value problems; thermoviscoelasticity, wave propagation.

**[TAM 7590 Boundary Element Methods**
Spring. 4 credits. Next offered 2009–2010.
Topics include a variety of applications of the boundary element method. Examples are: potential theory, linear elasticity, elasto-plasticity, micro and nano-electro-mechanical systems, meshfree boundary methods.]

## Dynamics and Space Mechanics

**TAM 5700 Intermediate Dynamics**
Fall. 3 credits.
Topics include Newtonian mechanics; motion in rotating coordinate systems; introduction to analytical mechanics; virtual work, Lagrangian mechanics; Hamilton's principle; small vibration and stability theory. Newtonian-Eulerian mechanics of rigid bodies; and gyroscopes. As time allows, introduction to orbital mechanics and chaos may be offered.

**TAM 5780 Nonlinear Dynamics and Chaos**
Spring. 3 credits. Prerequisite: MATH 2930 or equivalent.
Introduction to nonlinear dynamics, with applications to physics, engineering, biology, and chemistry. Emphasizes analytical methods, concrete examples, and geometric thinking. Topics include one-dimensional systems; bifurcations; phase plane; nonlinear oscillators; and Lorenz equations, chaos, strange attractors, fractals, iterated mappings, period doubling, renormalization.

**[TAM 6680 Elastic Waves in Solids with Applications**
Spring. 3 credits. Next offered 2009–2010.
Waves in one-dimensional elastic solids; two-dimensional systems; waves in infinite media, plates and rods; significant emphasis on measurements and applications.]

**[TAM 6710 Hamiltonian Dynamics**
Spring. 3 credits. Prerequisite: TAM 5700 or equivalent. Next offered 2009–2010.
Course topics include review of Lagrangian mechanics, Kanes equations, Hamiltons principle, Hamiltons, canonical equations, Lie transforms, Hamilton-Jacobi theory; KAM theory; and Melnikovs method.]

**TAM 6720 Celestial Mechanics (also ASTRO 6579)**
Spring. 3 credits.
Topics include description of orbits; 2-body, 3-body, and n-body; Hill curves, libration points and their stability; capture problems; osculating orbital elements, perturbation equations; effects of gravitational potentials, atmospheric drag, and solar radiation forces on satellite orbits; and secular perturbations, resonances, mechanics of planetary rings.

**[TAM 6730 Mechanics of the Solar System (also ASTRO 6571)**
Spring. 3 credits. Prerequisite: advanced undergraduate course in dynamics. Next offered 2009–2010.
Topics include gravitational potentials, planetary gravity fields; free and forced rotations; Chandler wobble, polar wander, and damping of nutation.]

**TAM 6750 Nonlinear Vibrations**
Fall. 3 credits. Prerequisite: TAM 5780 or equivalent.
Dynamics of nonlinear oscillators, including free and forced vibrations of both conservative and limit cycle oscillators, parametric excitation, systems of two, and N-coupled oscillators. Mathematical techniques include perturbation methods, center manifold reduction, and differential-delay equations.

**[TAM 7680 Elastic Waves in Solids**
Fall. 3 credits.]

**TAM 7760 Applied Dynamical Systems (also MATH 7170)**
Spring. 4 credits.
For description, see MATH 7170.

**[TAM 7609 Mechanics of Terrestrial Locomotion**
Spring. 3 credits. Prerequisite: TAM 5700, MAE 5710, or A+ level understanding of any sophomore or above mechanics course. Next offered 2009–2010.
The energetics and stability of people, other legged animals and robots are studied by mechanical analysis of simple models.]

## Special Courses, Projects, and Thesis Research

**TAM 4130 Introduction to Nuclear Science and Engineering (also AEP/CHEME/ECE/NSE 4130; MAE 4580)**
Fall. 3 credits. K. B. Cady.
For seniors and M.Eng. students interested in nuclear energy. Topics are presented at the level of the course text: Lamarsh and Baratta, *Introduction to Nuclear Engineering,* 3rd ed. and includes the fundamentals of nuclear science and engineering: nuclear structure, radioactivity, and reactions; interaction of radiation with matter; radiation protection and shielding; the neutron chain reaction and its control; light water reactors, isotope separation, fuel reprocessing, and waste disposal; heat transfer, accidents, atmospheric dispersion, and reactor licensing and safety.

**TAM 4910–4920 Project in Engineering Science**
491, fall; 492, spring. 1–4 credits TBA.
Projects for undergraduates under the guidance of a faculty member.

**TAM 7960–8000 Topics in Theoretical and Applied Mechanics**
Fall, spring. 1–3 credits TBA.
Special lectures or seminars on subjects of current interest. Topics are announced when the course is offered.

**TAM 8900 Master's Degree Research in Theoretical and Applied Mechanics**
Fall, spring. 1–15 credits TBA. S–U grades.
Thesis or independent research at the M.S. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

**TAM 9900 Doctoral Research in Theoretical and Applied Mechanics**
Fall, spring. 1–15 credits TBA. S–U grades.
Thesis or independent research at the Ph.D. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

# FACULTY ROSTER

Abel, John F., Ph.D., U. of California, Berkeley. Prof. (Emeritus), Civil and Environmental Engineering, Emeritus

Afshari, Ehsan, Ph.D., California Inst. of Technology. Asst. Prof., Electrical and Computer Engineering

Ahner, Beth A., Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Biological and Environmental Engineering

Albonesi, David H., Ph.D., U. of Massachusetts. Assoc. Prof., Electrical and Computer Engineering

Albright, Louis D., Ph.D., Cornell U. Prof., Biological and Environmental Engineering

Allmendinger, Richard, Ph.D., Stanford U. Prof., Earth and Atmospheric Sciences

Allmon, Warren D., Ph.D., Harvard U. Hunter R. Rawlings III Professor of Paleontology, Earth and Atmospheric Sciences

Andronicos, Christopher L., Ph.D., Princeton U. Assoc. Prof., Earth and Atmospheric Sciences

Aneshansley, Daniel J., Ph.D., Cornell U. Prof., Biological and Environmental Engineering

Angenent, Largus T., Ph.D., Iowa State U. Assoc. Prof., Biological and Environmental Engineering

Anton, A. Brad, Ph.D., California Inst. of Technology. Assoc. Prof., Chemical and Biomolecular Engineering

Apsel, Alyssa B., Ph.D., Johns Hopkins U. Clare Boothe Luce Assoc. Professor of Electrical and Computer Engineering

Aquino, Wilkens, Ph.D., U. of Illinois. Asst. Prof., Civil and Environmental Engineering

Archer, Lynden A., Ph.D., Stanford U. Marjorie L. Hart '50 Professor of Engineering, Chemical and Biomolecular Engineering

Arms, William, Ph.D., U. of Sussex (U.K.). Prof., Computer Science

Ast, Dieter G., Ph.D., Cornell U. Prof., Materials Science and Engineering

Avedisian, C. Thomas, Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering

Baeumner, Antje J., Ph.D., U. of Stuttgart (Germany). Assoc. Prof., Biological and Environmental Engineering

Bailey, Graeme, Ph.D., U. of Birmingham (U.K.). Prof., Computer Science

Baker, Shefford P., Ph.D., Stanford U. Assoc. Prof., Materials Science and Engineering

Bala, Kavita, Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Computer Science

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