COLLEGE OF ENGINEERING

ADMINISTRATION

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Michael Spencer, associate dean for research, graduate studies and professional education

Zellman Warhaft, associate dean for diversity and faculty recruitment

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Cathy Long, assistant dean for administration

Marsha Pickens, assistant dean for alumni affairs and development

David Gries, associate dean for undergraduate programs

Betsy East, assistant dean for student services

FACILITIES AND SPECIAL PROGRAMS

Most of the academic units of the College of Engineering are on the Joseph N. Pew, Jr. Engineering Quadrangle. Facilities for the School of Applied and Engineering Physics are located in Clark Hall on the College of Arts and Sciences campus, and facilities for the Department of Biological and Environmental Engineering are centered 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 and programs contribute to opportunities for study and research.

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

Center for Applied Mathematics. A cross-disciplinary center that admininsters a graduate program.

Center for Nanoscale Systems in Information Technologies. A National Science Foundation Nanoscience and Technology Center whose mission is to explore new methods for creating nanoscale devices for use in information technologies. The facilities for this center are distributed between Clark Hall and the Engineering Quadrangle.

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

Center for Theory and Simulation in Science and Engineering. A supercomputer facility used for advanced research in engineering and the physical and biological sciences.

Cornell High Energy Synchrotron Source (CHESS). 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 Nanofabrication Facility (part of the National Science Foundation–funded National Nanofabrication Users Network). A center that provides equipment and services for research in the science, engineering, and technology of nanometer-scale structures for electronic, chemical, physical, and biological applications.

Cornell Waste Management Institute. A research, teaching, and extension program within the Center for Environmental Research that addresses the environmental, technical, and economic issues associated with solid waste; one facility sponsored by the institute is the Combustion Simulation Laboratory in the Sibley School of Mechanical and Aerospace Engineering.

Institute for the Study of the Continents. An interdisciplinary organization that promotes research on the structure, composition, and evolution of the continents.

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

Laboratory of Plasma Studies. A center for research in plasma physics.

Cornell Center for Materials Research. An interdisciplinary facility with substantial support from the National Science Foundation, providing sophisticated scientific measurement and characterization equipment for materials research.

National Astronomy and Ionosphere Center. The world's largest radio-radar telescope facility, operated by Cornell in Arecibo, Puerto Rico.

National Earthquake Engineering Research Center. A facility recently established by the National Science Foundation and a group of universities in New York State to study response and design of structures in earthquake environments.

Nanobiotechnology Center. A National Science Foundation Science and Technology Center whose mission is to develop nanoscale tools for use in the life sciences. The facilities of this center are distributed between Clark Hall, Kimball Hall, and the Biotechnology Center.

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

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

Program of Biomedical Engineering. A cross-disciplinary field that administers the graduate field of Biomedical Engineering.

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

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

The programs listed on this page 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, master of engineering (with field designation), master of science, and doctor of philosophy.

General academic information concerning the bachelor of science degree is given here under the heading "Undergraduate Study." Curricula for major studies are described under the various academic areas.

Programs leading to the master of science and doctor of philosophy 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.* The professional Master of Engineering programs and cooperative programs with the Johnson Graduate School of Management are described below.

UNDERGRADUATE STUDY

Bachelor of science (B.S.) degrees are offered in the following areas:*

Biological Engineering†

Chemical Engineering

Civil Engineering

Computer Science

Electrical and Computer Engineering

Engineering Physics

Earth and Atmospheric Sciences

Independent Major

Materials Science and Industrial Engineering

Mechanical Engineering

Operations Research and Industrial Engineering

Students in the College of Engineering begin their undergraduate studies in the Common Curriculum, which is administered by the faculty members of the College Curriculum Governing Board (CCGB) through the associate dean for undergraduate programs and Engineering Advising. Subsequently most students enter *field* programs, which are described separately for each academic area. Criteria for entrance into the field programs are described in the section titled "Affiliation with a Field Program." Alternatively students may enter the *Independent Major* (described below), which permits them to pursue a course of study adapted to individual interests.

Students interested in bioengineering may arrange a suitable curriculum through the bioengineering option, the bioengineering minor, the biomedical engineering minor, or the Independent Major. Students interested in supplementing their field program with formal study in another traditional area of engineering may wish to consider one of the engineering minors offered by the college. Information about both the bioengineering option and engineering minors is available in Engineering Advising, 167 Olin Hall. Students interested in environmental engineering and science may pursue the environmental option offered by the School of Civil and Environmental Engineering and the Department of Biological and Environmental Engineering, or the science of earth systems (SES) option offered by the Department of Earth and Atmospheric Sciences.

*Biological engineering, chemical engineering, civil engineering, electrical engineering, engineering physics, materials science and engineering, and mechanical engineering are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology.

†To major in biological engineering, students normally enroll in the College of Agriculture and Life Sciences for the first three years, and jointly in that college and the College of Engineering for the final year. Students initially enrolled in the College of Engineering, however, may affiliate with the field of biological and environmental engineering and complete the degree solely within that college.

Requirements for Graduation

To receive the Bachelor of Science degree, students must meet the requirements of the Common Curriculum, as set forth by the College of Engineering, including the requirements of the field program, as established by the school or department with which they become affiliated. Students must meet the Common Curriculum as explained below. (Further explanation of the revised Common Curriculum and field flow charts are provided in the 2003–2004 edition of *The Engineering Undergraduate Handbook*.)

Course Category	*Credits*
1) Mathematics	16
2) Physics (depending on field)	8–12
3) Chemistry (depending on field)	4–8
4) First-year writing seminar*	6
5) Computer programming	4
6) Engineering distribution (3 courses)	
a. One Introduction to Engineering (ENGRI)	3
b. Two other engineering distribution courses (ENGRD)	6
7) Liberal studies distribution (6 courses min.)	18 (min.)
8) Approved electives	6
9) Field program	
a. Field required courses	30 cr. min.
b. Field approved electives	9
c. Courses outside the field	9

*One writing-intensive technical course or a course in technical or scientific writing must also be taken; this course may simultaneously satisfy some other requirement.

From 123 to 133 credits are required for graduation; the specific number of required credits varies depending on which field program is chosen (see field curricula for specific field requirements). Two terms of physical education must be taken in the freshman year, and students must demonstrate proficiency in swimming to satisfy a university requirement.

Mathematics

The normal program in mathematics includes MATH 191 (or 190), 192, 293, and 294. Every student must attain a grade of at least C- in MATH 191 (or 190), 192, 293, and 294, or other courses that may be approved as substitutes for these courses. If this requirement is not met the first time a course is taken, the course must be repeated immediately and a satisfactory grade attained before the next course in the sequence may be taken. Failure to achieve at least a C- the second time around will generally result in withdrawal from the engineering program. Courses that are taken a second time in order to meet this requirement do not yield additional credit toward a degree.

Physics

The normal program in physics includes PHYS 112, 213, and 214 or the corresponding honors courses (PHYS 116, 217, and 218). Engineering students are required to have attained a minimum grade of C- in MATH 191 or equivalent before taking PHYS 112. *The same minimum grade is required in each subsequent mathematics course before taking the physics course for which it is a prerequisite (e.g., C- in MATH 192 before taking PHYS 213, or C- in MATH 293 before taking PHYS 214). Students in the fields of BEE, CHEME, CEE, COM S, EAS (geoscience and SES options), or OR&IE may substitute CHEM 208 for PHYS 214.

Chemistry

CHEM 211 or 207 is required for all students.

CHEM 211 is a course designed for students who do not intend any further study in chemistry. Typically, CHEM 211 is taken during the freshman year, but students who wish to complete the physics program (PHYS 112, 213, and 214) first may postpone CHEM 211 until the sophomore year.

In general, students intending to affiliate with the following departments and schools usually take CHEM 211: Applied and Engineering Physics, Computer Science, Electrical and Computer Engineering, Materials Science and Engineering, Mechanical and Aerospace Engineering, and Operations Research and Industrial Engineering. Students considering Chemical Engineering must take CHEM 207 in the fall of their freshman year, to be followed by CHEM 208 in the spring term. All students considering the environmental option in Civil Engineering, the science of earth systems option in Earth and Atmospheric Sciences, or a health-related career such as medicine, should take the CHEM 207–208 sequence.

First-Year Writing Seminars

Each semester of their freshman year, students choose a First-Year Writing Seminar from among more than one hundred courses offered by over thirty different departments in the humanities, social sciences, and expressive arts. These courses offer the student practice in writing English prose. They also assure beginning students the benefits of a small class.

Technical Writing

Cornell's engineering college has an upper-level technical-writing requirement that students can fulfill by choosing one of the six options below. More information about some of these options is available at www.engineering.cornell.edu/ECP/index.htm.

1) ENGRC 350 or ENGRC 335, taught by the Engineering Communications Program
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 might satisfy the college's technical-writing requirement. More information is available at www.engineering.cornell.edu/ECP/Writing-IntensiveCoop.htm.
3) An officially designated Writing-Intensive (W-I) engineering course:
    - ENGRD/AEP 264
    - CHE 432
    - MSE 403 & 404 (both)
    - MSE 405 & 406 (both)
    - MAE 427
    - BEE 450 with co-registration either in ENGRC 301, a one-credit attachment that extends the writing done in this course (by permission of 450 instructor), or in BEE 493
    - BEE 473 with co-registration in ENGRC 301 (by permission of 473 instructor) or in BEE 493
    - BEE 489 with co-registration in ENGRC 301 (by permission of 489 instructor) or in BEE 493.
4) ENGRC 302, a one-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 done in his/her 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. May be taken more than once, with different courses. By permission of engineering instructor.
5) COMM 260, 263, or 352, taught by the Department of Communication (in the College of Agriculture and Life Sciences)
6) A petition. Occasionally, a student realizes that he/she will be doing a significant amount and variety of technical writing elsewhere in the engineering college. It may be appropriate for the student to submit a petition to the College Curriculum Governing Board's Subcommittee on Technical Writing, asking for permission to use his/her upcoming writing (not past writing) to

meet the technical-writing requirement. More information on criteria and submitting a petition is available at www.engineering.cornell.edu/ECP/Information.html.

Computing

To fulfill the computer programming requirement, students normally take COM S 100, Introduction to Computer Programming, during their freshman year.

Before taking COM S 100, some students choose to take COM S 099, Fundamental Concepts of Computer Programming, offered in the fall semester. COM S 099 is a two-credit S-U course designed for students with virtually no programming experience. Basic programming concepts and problem analysis are studied. An appropriate high-level programming language is used. Students with previous programming experience should not take this course. COM S 099 may not be used as credit toward graduation.

Engineering Distribution

Three engineering distribution courses (nine credits) are required. One course must be an Introduction to Engineering course (designated by ENGRI) to be taken by the student during his/her freshman year. The Introduction to Engineering course will introduce students to the engineering process and provide a substantive experience in an open-ended problem-solving context. See the Introduction to Engineering course listing for current course offerings.

The other two distribution courses must be selected from two different categories listed below. A student may use any one of the possible substitutions described.

1) *Scientific computing*
   - ENGRD 211, Computers and Programming
   - ENGRD 241, Engineering Computation
   - ENGRD 321, Numerical Methods in Computational Molecular Biology
   - ENGRD 322, Introduction to Scientific Computation
2) *Materials science*
   - ENGRD 261, Introduction to Mechanical Properties of Materials: From Nanodevices to Superstructures
   - ENGRD 262, Electronic Materials for the Information Age
3) *Mechanics*
   - ENGRD 202, Mechanics of Solids
   - ENGRD 203, Dynamics

Students in the field program in Engineering Physics may substitute A&EP 333 for ENGRD 203.

4) *Probability and statistics*
   - ENGRD 270, Basic Engineering Probability and Statistics

Students in the field program in Electrical and Computer Engineering may substitute ECE 310 for ENGRD 270. Students in the field program in Engineering Physics may substitute ECE 310 or MATH 471 for ENGRD 270. Students in the field programs in Civil Engineering and Biological Engineering may substitute CEE 304 for ENGRD 270.

5) *Electrical sciences*
   - ENGRD 210, Introduction to Circuits for Electrical and Computer Engineers
   - ENGRD 230, Introduction to Digital Logic Design
   - ENGRD 264, Computer-Instrumentation Design
6) *Thermodynamics and energy balances*
   - ENGRD 219, Mass and Energy Balances
   - ENGRD 221, Thermodynamics
7) *Earth and life sciences*
   - ENGRD 201, Introduction to the Physics and Chemistry of the Earth
   - ENGRD 251, Engineering for a Sustainable Society
   - ENGRD 260, Principles of Biological Engineering
8) *Biology and chemistry*
   - ENGRD 252/A&EP 252, The Physics of Life
   - BIO G 101 and 103, Biological Sciences, Lecture and Laboratory
   - BIO G 105, Introductory Biology
   - BIO G 107, General Biology (summer only)
   - CHEM 389, Physical Chemistry I

Some fields require a specific engineering distribution course as a prerequisite for the upperclass course sequence. These requirements are:

Biological and Environmental Engineering: ENGRD 202

Chemical and Biomolecular Engineering: ENGRD 219

Civil Engineering: ENGRD 202

Computer Science: ENGRD 211 (co-enrollment in COM S 212 strongly recommended)

Electrical and Computer Engineering: ENGRD 230

Earth and Atmospheric Sciences: ENGRD 201

Materials Science and Engineering: ENGRD 261

Mechanical Engineering: ENGRD 202

Operations Research and Engineering: ENGRD 270

Liberal Studies Distribution

The following liberal studies distribution requirements begin with the class entering in 2003. Students who entered before that may choose to use the new requirements.

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 true liberal education. A minimum of six courses (totaling at least 18 credits) is 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 courses must be from the first three groups (CA, HA, LA).
- At least two of the six courses must be at the 200 level or higher.

Please refer to the web site of Cornell Engineering Advising (**www.engineering.cornell.edu/studentServices/advising.cfm**) for access to a complete listing of acceptable courses in those groups, or a list of courses is available in Engineering Advising, 167 Olin Hall.

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).

2. Historical Analysis (HA)

Courses in this group interpret continuities and changes—political, social, economic, diplomatic, religious, intellectual, artistic, 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.

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.

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.

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).

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

- Approved electives—six credits required (approved by the academic adviser)

Because these courses should help develop and broaden the skills of the engineer, advisers will 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 field program or another part of the curriculum (Note: No ROTC courses may be used as approved electives unless they are co-listed by an academic department.)

- Field-approved electives—nine credits (approved by engineering field program faculty and field faculty advisers). Students should refer to the field program curricula for descriptions of courses that meet this category.
- To ensure breadth of engineering studies, field programs will also include nine credits of courses outside the field.

Social Issues of Technology

It is important for engineers to realize the social and ethical implications of their work. Consequently, in selecting their humanities, social sciences, 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 section). These courses may provide students with an important perspective on their studies and their future careers.

Engineering Advising

From the time students enter the college as freshmen until they are affiliated with a major field (*normally* prior to the second semester of the sophomore year), they are under the administration of Engineering Advising, 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 counseling. Also located in Olin Hall are the LIFE Program, Minority Programs, and Women's Programs, which are primary resources for counseling, support, tutoring, and networking opportunities.

Freshman Year Requirements

By the end of the freshman year, engineering students are expected to have completed (or received credit for) the following core requirements:

- MATH 191 (or 190) and MATH 192
- Two of the following: CHEM 211, 207, 208, PHYS 112, 213, 214*
- COM S 100
- Two First-Year Writing Seminars
- One Introduction to Engineering course (ENGRI designation)
- Two Physical Education courses

*Students with an interest in pre-med (or other health-related careers), Chemical Engineering, the environmental option in Civil Engineering, or the science of earth systems option in Earth and Atmospheric Sciences should enroll in the CHEM 207–208 sequence during their freshman year.

Affiliation with a Field Program

Students must apply for affiliation with a field program during the first term of their sophomore year, although earlier affiliation may be granted at the discretion of the field. This is done by visiting the undergraduate field consultant's office in the field of their choice and completing the Application for Field Affiliation form. To affiliate with a field program, students must (1) have a 2.0 cumulative grade point average and (2) have satisfied the field's course and grade requirements as specified below:

(Please note that fields may impose alternative affiliation requirements for students applying for affiliation later than the first semester of the sophomore year.)

Field Program	*Courses and Minimum Grade Requirements*
Biological Engineering	No more than one grade below C- in mathematics and science courses and BEE 151 or its equivalent
Chemical Engineering	No more than one grade below C- in chemistry, mathematics, physics, or chemical engineering courses and a 2.2 GPA in mathematics, science, and chemical engineering courses
Civil Engineering	A 2.0 GPA in all engineering and science courses and a grade of C- or better in ENGRD 202 (for students in the environmental option who do not take ENGRD 202 prior to affiliation, a grade of C- or better in CHEM 208 is required)
Computer Science	All potential affiliates are reviewed on a case-by-case basis relative to the following criteria:

- a grade of C or better in all completed **critical COM S courses and critical MATH courses**
- a GPA of 2.7 or better in all completed **critical COM S courses**. COM S 211, 212, and 280 must be part of the GPA computation.
- a GPA of 2.7 or better in all completed **critical MATH courses**. MATH 192 and 293 or MATH 112/122 and 221 must be part of the GPA computation.

Critical COM S courses:	COM S 211, 212, 280, 312, 314, 321, 322, 414, 421, 381, 481, and 482
Critical MATH courses:	MATH 112, 122, 192, 221, 222, 223, 224, 293, 294, 336, 356 and ENGRD 270

Courses used to determine affiliation may be repeated if the original course grade is below a "C." The most recent grade is used when a course is repeated. Qualifying courses must be taken at Cornell.

Electrical & Computer Engineering	Be in good academic standing in the College of Engineering. Must have completed with a grade of C+ or better MATH 293, PHYS 213, and either ENGRD/ECE 210 (4 credits) or ENGRD 230
	Must have an average GPA of at least 2.5 in the following courses if completed: MATH 192, 293, 294, PHYS 213, ENGRD 211, 230, ECE/ENGRD 210 (4 credits)
Engineering Physics	A grade of B- or better in all required mathematics and physics courses
Geological Sciences	Good academic standing in the College of Engineering
Materials Science & Engineering	A grade of C- or better in all physics and chemistry courses and a grade of C or better in ENGRD 261 or ENGRD 262
Mechanical Engineering	A grade of C- or better in mathematics and science courses and ENGRD 202
Operations Research & Engineering	A grade of C- or better in MATH 191, 192, ENGRD 270 and a 2.0 GPA in all mathematics, science, and engineering courses (both overall and in the term immediately prior to affiliation)

Students must be affiliated or conditionally affiliated 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 Option

A special academic option, intended for superior students, is the dual degree program, in which both a Bachelor of Science and either a Bachelor of Arts or Bachelor of Fine Arts degree can 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. Those interested should contact the appropriate coordinators of dual degree programs at the following locations: 55 Goldwin Smith Hall (for Arts and Sciences), 135 East Sibley (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 fields of engineering, generally requires at least one semester beyond the usual four years. Students affiliate with one field following normal procedures and then petition to enter a second field before the end of their junior year. All the requirements of both fields must be satisfied. Further information is available from Engineering Advising, 167 Olin Hall, and the individual field consultant offices.

Independent Major

Individually arranged courses of study under the Independent Major are possible for those students whose educational objectives cannot be met by one of the regular field programs. Often the desired curriculum is in an interdisciplinary area. Each program is developed by the student in consultation with faculty advisers and must be approved by the Independent Major Committee, which is responsible for supervising the student's work.

Students should apply to enter the Independent Major during the sophomore year. A student should seek assistance in developing a coherent program from professors in the proposed major and minor subject areas. If approved, the program is the curricular contract to which the student must adhere.

Every curriculum in the Independent Major, with the exception of certain faculty-sponsored programs, must comprise an engineering major and an educationally related minor. The major may be in any subject area offered by schools or departments of the college; the minor may be in a second engineering subject area or in a logically connected nonengineering area. The combinations must clearly form an engineering education in scope and in substance and should include engineering design and synthesis as well as engineering sciences. In addition to 48 credits in the major and minor subjects, including at least 32 credits in engineering courses, each program includes the normally required courses in humanities and social sciences and approved electives.

Further information about the Independent Major may be obtained from Engineering Advising, 167 Olin Hall.

Important note: because no single standardized curriculum exists, the Independent Major is not accredited. 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.

Engineering Minors

The engineering minor is a supplement to the regular bachelor's degree programs in the college, including the Independent Major, and recognizes formal study of a particular technical subject area in engineering normally outside the student's major. Therefore, it may be necessary for some students choosing to complete the requirements for an engineering minor to spend more than the traditional eight semesters to complete their studies at Cornell. In many cases, however, courses fulfilling minor requirements may also satisfy other degree requirements (e.g., distribution courses, approved electives, or field-approved electives). Students undertaking a minor are expected to complete the requirements during the time of their continuous undergraduate enrollment at Cornell.

To complete an engineering minor, an undergraduate engineering student must

- be enrolled in a major field program that approves the participation of its affiliates in the desired minor.
- successfully complete all the requirements for a bachelor of science degree in engineering.
- satisfactorily complete six courses (18 credit minimum) as stipulated in a college-approved minor.

Students may apply for certification of an engineering minor at any time after the necessary course work has been completed in accordance with published standards. Students who receive certification in an approved engineering minor will be recognized by means of an official notation on their Cornell transcript following graduation.

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

Applied Mathematics (T&AM)

Biological Engineering (BEE)

Biomedical Engineering (BMEP)

Civil Infrastructure (CEE)

Computer Science (COM S)

Electrical and Computer Engineering (ECE)

Engineering Management (CEE)

Engineering Statistics (OR&IE)

Environmental Engineering (BEE/CEE)

Geological Sciences (EAS)

Industrial Systems and Information Technology (OR&IE)

Information Science (COM S)

Materials Science and Engineering (MS&E)

Mechanical Engineering (M&AE)

Operations Research and Management Science (OR&IE)

Additional information on specific minors can be found in the departmental sections of this publication, the *Engineering Undergraduate Handbook*, the undergraduate field office of the department offering the minor, and Engineering Advising.

Minor in Applied Mathematics

To complete the minor, the student must take at least six (6) courses beyond MATH 294, to be chosen as follows:

a) No more than 1 course may be chosen from any one of the groups 1, 2, 3, or 4.

b) At least 3 courses must be chosen from groups 5 and 6.

c) No more than 1 200-level course may be chosen.

d) No more than 1 course may be chosen that is offered by the student's major department.

1. Analysis

T&AM 310 Advanced Engineering Analysis I

MATH 311 Introduction to Analysis

MATH 420 Differential Equations and Dynamical Systems

A&EP 321 Mathematical Physics I

2. Computational methods

COM S 322 Introduction to Scientific Computation

CEE 241 Engineering Computation

OR&IE 320 Optimization I

3. Probability and Statistics

OR&IE 270 Basic Engineering Probability and Statistics

OR&IE 360 Engineering Probability and Statistics II

EE 310 Introduction to Probability and Random Signals

CEE 304 Uncertainty Analysis in Engineering

4. Applications

A&EP 333 Mechanics of Particles and Solid Bodies

CHEME 323 Fluid Mechanics

CEE 331 Fluid Mechanics

CEE 371 Structural Behavior

EE 425 Digital Signal Processing

M&AE 323 Intro to Fluid Mechanics

MS&E 303 Thermodynamics of Condensed Systems

5. Advanced Courses

Only one of the following three may be chosen:

T&AM 311 Advanced Engineering Analysis II

MATH 422 Applied Complex Analysis

A&EP 322 Mathematical Physics II

Only one of the following two may be chosen:

EE 411 Random signals

OR&IE 361 Introductory Engineering Stochastic Processes I

Only one of the following two may be chosen:

COM S 381 Introduction to Theory of Computing

COM S 481 Introduction to Theory of Computing

Only one of the following two may be chosen:

M&AE 571 Applied Dynamics

T&AM 570 Intermediate Dynamics

Also, you can choose from:

COM S 482 Introduction to the Design of Algorithms

OR&IE 321 Optimization II

OR&IE 431 Discrete Models

OR&IE 435 Introduction to Game Theory

OR&IE 462 Introductory Engineering Stochastic Processes II

EE 522 Nonlinear Systems

T&AM 578 Nonlinear Dynamics and Chaos

T&AM 610 Methods of Applied Math I

T&AM 611 Methods of Applied Math II

6. Math Courses

Any 300+ level course offered by the Mathematics Department in algebra,

analysis, probability/statistics, geometry or logic, with the following exceptions:

i) MATH 311 or MATH 420, if any course from group 1 is chosen.

ii) MATH 422, if T&AM 311 or A&EP 322 are chosen from group 5.

Academic Standards: A letter grade of C or better for each course in the minor.

Required Courses

COM S/ENGRD 211 Computers and Programming

COM S 321 Numerical Methods in Computational Biology

or COM S/ ENGRD 322 Introduction to Scientific Computing

or COM S 421 Numerical Analysis

The Bioengineering Option and the Biological Engineering and Biomedical Engineering Minors

Students wishing to apply the concepts and methods of the engineering, computational and physical sciences to living systems or health issues may pursue one of three courses of study:

(1) the bioengineering option, requiring completion of two to three bioengineering courses and one to two biological sciences courses (12 credit hours minimum) and one credit hour of Bioengineering Seminar (BMEP 501). The student will receive official notation on their transcript. Further information is available in Engineering Advising, 167 Olin Hall.

(2) the biological engineering minor, requiring six courses (18 credit hours minimum) including BEE 350, two analysis courses, two application courses, and one basic science course. This minor provides the student an opportunity to further their understanding of living systems and the basic transport processes that occur in these systems. Further information is available from the BEE Program Coordinator, 207 Riley-Robb Hall.

(3) the biomedical engineering minor, requiring six courses (18 credit hours minimum) from at least four of five different groups—Introductory Biology, Advanced Biology, Molecular and Cellular BME, BME Analysis of Physiological Systems, BME Applications. Further information is available from the Biomedical Engineering Program coordinator, 270 Olin Hall.

International Programs

All students who plan to study abroad apply through Cornell Abroad; please see the Cornell Abroad program description in the introductory section of *Courses of Study*.

An international perspective, sensitivity to other cultures, and the ability to read and speak a second language are increasingly important to today's engineers. In keeping with the university goals of internationalizing the curriculum, the College of Engineering encourages students to study or work abroad during their undergraduate years. For further information on these and other opportunities to add an international dimension to your undergraduate education, see the staff in Engineering Advising, 167 Olin Hall. Students who seek advice on obtaining an international co-op work experience should visit the Engineering Cooperative Education and Career Services office, 201 Carpenter Hall.

Engineering Communications Program

The Engineering Communications Program (ECP), created in 1987 at the urging of the College of Engineering faculty and employers of Cornell engineers, provides instruction in technical writing, oral presentation, and the use of graphics in both. Information about the ECP's courses and annual prizes, as well as the college's technical-writing requirement, is available at www.engineering.cornell.edu/ECP/index.htm. 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 having 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, do library and Internet research on engineering topics, and study real engineering situations in which ethics may have been breached.

Enrollment is 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.

Besides teaching its courses, members of the ECP are available to consult with the faculty teaching the officially designated "writing-intensive" technical courses. They oversee the communications component of the Writing-Intensive Co-op, sit on the College Curriculum Governing Board's Subcommittee on Technical Writing and the Subcommittee on Liberal Arts, and occasionally give talks to alumni/ae and student groups.

If you have any questions, please call 255-8558, come by the ECP's office (Hollister 425), or stop at any ECP member's office on the fourth floor of Hollister.

Engineering Cooperative Education Program

A special program for engineering undergraduates is the Engineering Cooperative Education Program, which provides an opportunity for students to gain practical experience in industry and other engineering-related enterprises before they graduate. By supplementing course work with carefully monitored, paid jobs, co-op students are able to explore their own interests and acquire a better understanding of engineering as a profession.

To be eligible, a student must have been enrolled at Cornell for four semesters prior to working, with a cumulative GPA of 2.7 or higher. (Students in Computer Science and Biological and Environmental Engineering are eligible, even though they may not be registered in the College of Engineering.) Applicants are interviewed by representatives of participating employers and select their work assignments from any offers they receive. Those students who are offered assignments and elect to join the program usually take their fifth-term courses at Cornell during the summer following their sophomore year and begin the first co-op work assignment that fall. They return to Cornell to complete term six with their classmates and then undertake a second work assignment with the same employer the following summer. Co-op students return to campus for their senior year and graduate with their class.

Further information may be obtained from the Engineering Cooperative Education and Career Services office, 201 Carpenter Hall.

MASTER OF ENGINEERING DEGREE PROGRAMS

One-year Master of Engineering (M.Eng.) programs are offered in 14 fields. These programs are discussed in this announcement in connection with the corresponding upperclass engineering field programs because the curricula are integrated. Cornell baccalaureate engineering graduates frequently continue their studies in the M.Eng. program, although the program is also open to qualified graduates of other schools. Prospective students should access the Master of Engineering web site (www.engineering.cornell.edu/grad) for program specifics. The M.Eng. degree fields and their academic departments under which they are administered are listed below.

M.Eng. (Aerospace): Mechanical and Aerospace Engineering

M.Eng. (Agricultural and Biological): Biological and Environmental Engineering

M.Eng. (Chemical): Chemical and Biomolecular Engineering

M.Eng. (Civil & Environmental): Civil and Environmental Engineering

M.Eng. (Computer Science): Computer Science

M.Eng. (Electrical): Electrical and Computer Engineering

M.Eng. (Engineering Physics): Applied and Engineering Physics

M.Eng. (Geology): Earth and Atmospheric Sciences

M.Eng. (Materials): Materials Science and Engineering

M.Eng. (Mechanical): Mechanical and Aerospace Engineering

M.Eng. (Engineering Mechanics): Theoretical and Applied Mechanics

M.Eng. (Nuclear): Nuclear Science and Engineering

M.Eng. (OR&IE): Operations Research and Industrial Engineering

M.Eng. (Systems): Systems Engineering

Admission:

Requirements for admission vary by field and prospective students should contact the appropriate field. In general, the standard M.Eng. application requirements include:

- Statement of Purpose
- Complete transcripts from each college or university you have attended
- At least two letters of recommendation
- Graduate Record Examinations (GRE) scores—may not be required by all fields

Many fields waive the GRE requirement and one of the letters of recommendation for students with Cornell Engineering B.S. degrees. Students should check with the appropriate field office for specific program requirements. A list of M.Eng. field links and general admission information is posted on the web at www.engr.cornell.edu/grad/meng/app.html.

The following M.Eng. options are offered:

- The Bioengineering Option
- The Financial Engineering Option
- The Manufacturing Option
- The Engineering Management Option
- The Systems Engineering Option

Each option is available to M.Eng. students in specific fields. The Master of Engineering Options web page, www.engr.cornell.edu/grad/meng/options.html, lists specific details including availability and contact information.

Cooperative Programs with the Johnson Graduate School of Management:

The Lester Knight Scholarship Program is designed to assist and encourage Cornell Engineering students and alumni interested in combining their engineering training with a business degree.

The Knight Scholarship Program offers three options or categories of financial support:

- The Alumni Knight Scholarship Option
- The Undergraduate Knight Scholarship Option
- The Six-Year Knight Scholarship Option

Each program has different qualifications and is open to Cornell engineering students and alumni at different stages of their educational or professional careers. Participation in the Knight Scholarship 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. Refer to the Knight Scholarship web site (www.engr.cornell.edu/grad/knight) for program specifics or contact the Office of Research, Graduate Studies, and Professional Education, 146 Olin Hall.

Early Admission Program:

Superior Cornell students who will have between one and eight credits remaining in their last undergraduate semester may petition the appropriate field representative for early admission to the M.Eng. program.

Program Options:

Cornell's Master of Engineering Program allows students to supplement their field curriculum with a program option. Students who choose a program option enroll in courses that satisfy elective requirements.

BIOMEDICAL ENGINEERING PROGRAM

Michael L. Shuler, director; Donald L. Bartel, associate director; William Lee Olbricht, director of graduate studies.

The Biomedical Engineering Program's (BMEP) charge is to bridge engineering, biology, and medicine. Students are educated to convert basic discoveries in biology and medicine into medically useful devices and therapies to improve human health. Biomedical engineers also contribute to biological discovery. The 30 Biomedical Engineering Graduate Field and program faculty represent 12 departments and six colleges (including Weill Medical College). The BME field offers research opportunities in biomedical mechanics; biomaterials; drug delivery, design, production, and metabolism; biomedical instrumentation and diagnostics; and system biology.

The BMEP currently administers the Biomedical Engineering Graduate Field and the M.S./Ph.D. degree programs. A Master of Engineering program in Biomedical Engineering (BME) is in the process of approval and is anticipated to be offered as early as fall 2004.

Minor in Biomedical Engineering

The BMEP also is responsible for a new minor program in biomedical engineering. Students graduating in the Class of 2006 and later must complete the minor as specified by BMEP. Students graduating in 2004 and 2005 may elect to complete the requirements in the Biomedical Engineering Minor offered by Theoretical and Applied Mechanics (T&AM).

Offered by: Biomedical Engineering Program

Administered by: Biomedical Engineering Program Director, 270 Olin Hall; Michael L. Shuler, 270 Olin Hall, mls50@cornell.edu, 255-7577

Eligibility: All undergraduates in the College of Engineering are eligible to participate in the Biomedical Engineering minor unless they are also pursuing the Bioengineering Option. (Students may participate in either the Bioengineering Option OR the Biomedical Engineering minor but not both.)

Educational Objectives: Biomedical engineering is the application of engineering principles and methods to a wide array of problems associated with human health. The field 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. The purpose of this minor is to allow students in the College of Engineering 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 recognition for their interest and capability in this rapidly growing area.

Menu of Courses: SEE BELOW

Academic Standards: A letter grade of C- or better for each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Requirements

Required Course: BMEP 501, Bioengineering Seminar (1 credit)

To complete the minor, the student also must take at least six (6) courses (minimum of 18 credits) from the five groups listed below, with at least four of the groups represented and four of which must be from Categories 3, 4, and 5. At least four of the six courses must be from outside the student's major.

Students who are considering the BME minor are asked to register with the Biomedical Engineering Program Office (270 Olin). A BME faculty adviser will be assigned and will approve the student's BME minor plan.

1. **Introductory Biology (maximum of 4 credits and one course towards BME minor)**

   BIOG 110 and ENGRI 101—Biological Principles and Introduction to Biomedical Engineering Analysis

   BIOG 101, 102, 103, and 104—Biological Sciences

   BIOG 105 and 106—Introductory Biology

   BIOG 107 and 108—General Biology

   A "5" on AP Biology Test

2. **Advanced Biology**

   BIOGM 330—Principles of Biochemistry, Individualized Instruction

   BIOGM 333—Principles of Biochemistry, Proteins, Metabolism, and Molecular Biology

   BIOGM 331 and 332—Principles of Biochemistry, Proteins and Metabolism and Principles of Biochemistry, Molecular Biology

   BIOAP 311—Introductory Animal Physiology Lectures

   BIOGD 281—Genetics

   BIONB 222—Introduction to Neurobiology

   BIOMI 290—General Microbiology Lectures

   BIOGD 389—Embryology

3. **Molecular and Cellular Biomedical Engineering**

   BMEP 301 (CHEME 401)*—Molecular Principles of Biomedical Engineering

   BMEP 302 (CHEME 402)*—Cellular Principles of Biomedical Engineering

   A&EP 252—The Physics of Life

   BEE 360—Molecular and Cellular Bioengineering

4. **BME Analysis of Physiological Systems**

   BMEP 401*—Biomedical Engineering of Metabolic and Structural Systems

   BMEP 402*—Information Exchange in BME Systems (planned for spring 2004)

M&AE 464—Orthopaedic Tissue Mechanics

M&AE 463—Neuromuscular Biomechanics

BEE 454—Physiological Engineering

CHEME 481—Biomedical Engineering

BIONB 330—Introduction to Computational Neuroscience

5. **Biomedical Engineering Applications**

A&EP 470—Biophysical Methods

BEE 450—Bioinstrumentation

BEE 453—Computer-Aided Engineering: Applications to Biomedical Processes

BEE 459—Biosensors and Bioanalytical Techniques

COM S 321—Numerical Methods in Computational Molecular Biology

ECE 402—CDE in Biomedical System Design

ECE 336—Nanofabrication

ECE 578—Computer Analysis of Biomedical Images

BEE 365—Properties of Biological Materials

MS&E 265 **OR** TXA 439—Biological Materials and Their Synthetic Replacements OR Biomedical Materials and Devices for Human Body Repair

M&AE 565—Biomechanical Systems—Analysis and Design

*A new M.Eng. degree in BMEP is currently being planned for fall 2004 pending New York State approval..The recommended sequence for admission to the M.Eng. BME will be BIOG 110 and ENGRG 101; any category 2 course; BMEP 301, 302, 401, and 402. The M.Eng. BME program will require knowledge of molecular and cellular BME, and of BME analysis of physiological systems.

ACADEMIC PROCEDURES AND POLICIES

Advanced Placement Credit

The College of Engineering awards a significant amount of advanced placement (AP) credit to entering freshmen 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 prior to the beginning of fall-term 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.

(1) They may enroll in a more advanced course in the same subject right away.

(2) They may substitute an elective course from a different area.

(3) They may 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 191 (or 190), 192, 293, and 294 are required.

First-term math (MATH 191). AP credit may be earned by:

- a score of 3, 4, or 5 on the CEEB BC exam, or
- a score of 5 on the CEEB AB exam, or
- a passing score on the Cornell departmental exam for first-term math.

First-year math (through MATH 192). AP credit may be earned by:

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

Physics: PHYS 112 and 213 are required.

PHYS 112. 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 *only* if the student has at least one semester of AP or transfer credit in first-term mathematics at the time of matriculation, or
- a passing score on the Cornell departmental exam for PHYS 112.

Note: Students who have received credit for PHYS 112 **may not** enroll in PHYS 213 unless concurrently enrolled in MATH 293.

PHYS 213. Students receiving a 5 on the Electricity and Magnetism portion of the C exam may choose to accept AP credit for PHYS 213 or placement in PHYS 217 with no AP credit for PHYS 213. For advice or more information contact the departmental representative at 607 255-6016.

Chemistry: CHEM 207 or CHEM 211 is required.

CHEM 207 or CHEM 211. 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 are successful in obtaining AP credit for CHEM 207 and who are considering majors in Chemical Engineering or Materials Science and Engineering should consider enrolling in CHEM 215. Those who are offered AP credit for CHEM 207 and then elect to take CHEM 215 will also receive academic credit for CHEM 207. You may want to discuss this option with your faculty adviser.

Computing: COM S 100 is required. AP credit may be earned 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 COM S 100.

Biology: Biology is not required of engineering students, although it is a popular option as an elective, especially for students who intend to pursue health-related careers. AP credit may be earned as follows:

- eight credits will be offered to students who receive a 5 on the CEEB AP exam;
- six 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 (for a total of six credits) 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 will be offered three credits which may be applied toward the Humanity/History category (a) of the Liberal Studies distribution requirement. Students who earn a score of 4 on the AP English Language and Composition exam will be offered three credits which may be applied toward the Expressive Arts (d) 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.

Modern 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 are entitled to three credits. In order to qualify for the CASE exam, the student must score at least 650 on a College Placement Test (taken either in high school or at Cornell during Orientation Week). A score of 2 on the CASE entitles the student to three credits, and a score of 3 entitles the student to six credits, which are equivalent to two courses. Modern language AP credits may be used to satisfy the foreign language category of the liberal studies distribution, or may meet an approved elective requirement, contingent on discussions with the faculty adviser.

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 207 and 208)
	B	4 credits (CHEM 207)
Mathematics	A, B, or C	4 credits (MATH 191/190)
Physics	A or B	4 credits for PHYS 112; 4 additional credits for PHYS 213 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 207 or CHEM 211)
Computer Science	6 or 7	4 credits (COM S 100)
Mathematics	6 or 7	4 credits
Physics	6 or 7	4 credits (PHYS 112)

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-term 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-term 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.

Transfer Credit for First-Year and Continuing Students

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, students must complete and submit a Transfer Credit Form (one form for each request), accompanied by a course description. (Transfer Credit Forms are available from Engineering Advising or the Registrar's Office and should be submitted prior to enrollment.) 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.
- To apply for transfer credit to satisfy requirements in mathematics, science, engineering courses, or First-Year Writing Seminars, a student must receive approval from the department offering an equivalent course at Cornell. The department certifying the course may require course materials, textbooks used, etc., in addition to the course description before approving the course.
- Departmental approval is not required to apply 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 of 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, as described in the Advanced Credit section.
- Following matriculation, students may apply up to 18 credits of transfer and/or Cornell extramural credit toward bachelor's degree requirements.
- No more than 72 total transfer credits (combination of those 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.

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 is determined by the fields.

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 actually means varies from field to field.

Requirements for freshman engineering students to be in good standing at the end of the first semester are as follows. 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 mathematics, science, and/or engineering
2. A C- or better in the mathematics course
3. A semester average of 2.0 or higher
4. No F, U, or INC grades

Requirements for unaffiliated second-semester freshmen and sophomores to be in good standing are as follows. 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 14 credits passed in courses that meet engineering degree requirements (normally at least two courses from mathematics, science, or engineering courses)
2. A C- or better in the mathematics course, if one was taken
3. A semester average of 2.0 or higher
4. No F, U, or INC grades

Academic Progress

The total number of credits required for graduation range from 123 to 133, depending on the field program. Therefore, an average semester credit load ranges from approximately 15 to 17 credits.

Because mathematics is pivotal to the study and practice of engineering, students must earn a grade of C- or better in MATH 191 (or 190), 192, 293, and 294. Those who fail to meet this standard are allowed to repeat a course once in the following semester. Failure to achieve at least a C- the second time will generally result in withdrawal from the

College of Engineering. Physics and advanced mathematics courses often have mathematics prerequisites, and having to repeat the prerequisite course may delay progress in the physics and mathematics 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 with exemplary academic records. The criteria for this honor are determined by the dean of the college. For 2003–2004, the requirement is a semester average of 3.4 or higher (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 Program

Graduating with Distinction

Meritorious students graduating with a bachelor of science 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 all engineering students with an overall GPA $\geq$ 3.5. Cum laude will also be awarded to all engineering students who received a semester GPA $\geq$ 3.5 in each of the last four semesters of attendance 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 pro-rated 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 all engineering students with an overall GPA $\geq$ 3.75 (based on all credits taken at Cornell).
- Summa cum laude will be awarded to all engineering students with an overall GPA $\geq$ 4.0 (based on all credits taken at Cornell).

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

Field Honors Program

To be eligible for field honors, a student must enter a program with and maintain a cumulative GPA of $\geq$ 3.5. If the student's major field has an approved honors program and both the GPA and program requirements are fulfilled, the faculty of the field may recommend that a student graduate with the additional diploma and transcript notation of "With Honors." For more specific information, see the field program outline in this catalog.

S-U Grades

Many courses offered by the university 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 C- or better in a course will receive a grade of S; those earning less than C- receive a grade of U. (Any 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 have previously 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 approved elective in the engineering curriculum.
- Students may only elect to enroll S-U in one course each semester in which the choice between letter grade and S-U is an option. (Additional courses offered "S-U only" may be taken in the same semester as the "elected S-U" course.)

The choice of grading option for any course is initially made during the pre-enrollment period. Grading options may be changed, however, by submitting a properly completed Add/Drop Form to the Engineering Registrar by 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.

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. They must also spend at least three semesters of this time affiliated with an engineering field program or with the College Program.

Students who are on a voluntary leave of absence are permitted to register for courses extramurally only with the approval of their field (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 bachelor'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 office responsible for assisting students with the transfer process is the Internal Transfer Division Office. 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—application forms are available in 167 Olin Hall. It is preferred that a student apply in the semester in which he/she is completing affiliation criteria for the desired field. Students who would enter the college as a second-semester sophomore or later must be accepted by a field program as part of the admission process. Students who would enter as a second-semester freshman or first-semester sophomore may be accepted into the college without the requirement of field affiliation but must be sponsored by a field program.

Students who hope to transfer into engineering should take courses in mathematics, chemistry, computer science, physics, and engineering that conform to the requirements of the Common Curriculum. Interested students should discuss their eligibility with an adviser 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, students must petition for a leave of absence for a specified period of time and receive written approval.

Affiliated students request leave through their fields. 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 field 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.

Leaves of absence are not generally granted for more than two years. A leave of absence granted during a semester goes into effect on the day it is requested and lasts for a *minimum of six months*. If a leave is requested after the twelfth 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 leaves of absence. If courses taken during a leave are to satisfy Cornell degree requirements, they 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 taken out 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 term 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 where the academic progress of a student is so poor that continuing into the next semester does not appear prudent. An example where a leave of absence would be required 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 only offered in the fall or the 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 field should request permission to rejoin in a letter to Engineering Advising; affiliated students should contact their field 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 engineering degree program sever all connection with the college. Unaffiliated students who wish to withdraw should do so through Engineering Advising. Affiliated students should contact their field office. If a withdrawal is requested during the semester, courses in which the student is enrolled must be dropped in accordance with applicable regulations.

Any 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 intra-university transfer process should be followed.

If students who have withdrawn subsequently wish to return, they 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 field.

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 only withdraws them 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 COOPERATIVE EDUCATION AND CAREER SERVICES

This office assists engineering students (freshmen through Ph.D.) in career development and job search issues, and administers the Engineering Cooperative Education Program (see separate entry under the Engineering Special Programs section). Individual advising and group seminars are available, and more than 200 national employers typically visit the office annually to recruit technical students and graduates; additional job opportunities are posted electronically. Both undergraduate and graduate students can use these services to pursue permanent or summer employment opportunities; however, students seeking co-op opportunities must meet specific requirements. Further information on all services is available from the Engineering Cooperative Education and Career Services Office, 201 Carpenter Hall (255-5006), and on the web at www.career.cornell.edu and www.engr.cornell.edu/coop.

APPLIED AND ENGINEERING PHYSICS

J. D. Brock, director; B. R. Kusse, associate director for undergraduate studies; A. L. Gaeta, director of graduate studies, R. A. Buhrman, T. A. Cool, H. G. Craighead, M. S. Isaacson, 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; senior research associate: E. J. Kirkland; instructor: M. J. Plisch; instructor: L. Wickham.

Bachelor of Science Curriculum

The undergraduate engineering physics curriculum 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 mathematics 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, the students may combine this physics base with a good background in a conventional area of engineering or applied science.

The industrial demand for engineering physics graduates with baccalaureates is high, and many students go directly to industrial positions where they work in a variety of 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 our 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, mechanical engineering, medical physics, mathematics, medicine, nuclear engineering, oceanography, and physics. The undergraduate program can also serve as an excellent preparation for medical school, business school, or specialization in patent law.

The Engineering Physics program 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/A&EP 110, The Laser and Its Applications in Science, Technology, and Medicine (a freshman Introduction to Engineering course); ENGRI/A&EP 130, Introduction to Nanoscience and Nanoengineering (a freshman Introduction to Engineering course); ENGRD/A&EP 264, Computer-Instrumentation Design (a recommended sophomore engineering distribution course); A&EP 330, Modern Experimental Optics (a junior/senior course); A&EP 363, Electronic Circuits (a sophomore/junior course); PHYS 410, Advanced Experimental Physics; and A&EP 438, Computational Engineering Physics (a senior computer laboratory).

Undergraduates who plan to enter the field program in Engineering Physics are advised to arrange their Common Curriculum with their developing career goals in mind. Students are also encouraged to take PHYS 112 or PHYS 116 during their first semester (if their advanced placement credits permit) and are recommended to satisfy the technical writing requirement with the engineering distribution course ENGRD 264. Engineering Physics students need to take only two engineering distribution courses, since A&EP 333, which they take in their junior year, counts as a third member of this category. Engineering Physics students are advised to take A&EP 363 in the spring semester of the sophomore year. Students with one semester of advanced placement in math, who have received a grade of A- or better in MATH 192, may wish to explore accelerating their mathematics requirements so as to enroll in A&EP 321 and 322 in the sophomore year. For advice on this option, consult with the A&EP associate director.

In addition to the requirements of the Engineering Common Curriculum,* the upperclass course requirements of the field program are as follows:

Course	*Credits*
A&EP 333, Mechanics of Particles and Solid Bodies	4
A&EP 355, Intermediate Electromagnetism	4
A&EP 356, Intermediate Electrodynamics	4
A&EP 361, Introductory Quantum Mechanics	4
A&EP 363, Electronic Circuits	4
A&EP 423, Statistical Thermodynamics	4
A&EP 434, Continuum Physics	4
PHYS 410, Advanced Experimental Physics	4
A&EP 321, Mathematical Physics I; or MATH 421 (applied mathematics)	4
A&EP 322, Mathematical Physics II; or MATH 422 (applied mathematics)	4

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

Total field credits=58 credit hours minimum.

*The Engineering Common Curriculum allows students to take only four courses each semester of their freshman year if they so desire. This course load is fully consistent with the requirements of the EP major, but entering students with strong preparation are encouraged to consider taking an additional course during one or both semesters of the freshman year 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 four credits of PHYS 410 required for the BS degree in Engineering Physics can be satisfied by successfully completing A&EP/PHYS 330. The remaining two credits of PHYS 410 can then be satisfied by taking PHYS 400 for two credits, provided that the experiments completed in PHYS 400 do not overlap with those in A&EP/PHYS 330. (A list of experiments that are not appropriate will be prepared by A&EP faculty and made available in the A&EP office.) If a student chooses this option, A&EP/PHYS 330 may also count as a technical elective, provided the remaining three technical electives are four credits each.

Choosing elective courses. A distinctive aspect of the Engineering Physics curriculum is the strong opportunity it provides students 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 one or more of a number of advanced technical and scientific areas. With at least seven technical and approved electives in the sophomore, junior, and senior years, Engineering Physics majors are encouraged to work closely with their adviser to develop a coherent academic program that is in accordance with those goals. For those students who look toward an industrial position after graduation, these 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 themselves particularly well for graduate study in any one of a number of fields. Various programs are described in a special brochure available from the School of Applied and Engineering Physics, Clark Hall. Students interested in these options are advised to consult with their EP adviser, a professor active in their area of interest, or with the associate director of the school, Professor Bruce Kusse.

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 (A&EP 490). 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.

The Engineering Physics program requires that a minimum of B- or better be attained in each physics and mathematics courses taken by a student before entering the Engineering Physics field unless approval is obtained from the A&EP associate director. To remain in good standing in the field, the engineering physics student is expected to pass every course for which he or she is registered, to earn a grade of C- or better in specifically required courses, and to attain each semester a grade-point average for that semester of at least 2.3.

Engineering Physics Honors Program

Eligibility

The bachelor of science degree with honors will be conferred upon those students who, while completing the requirements for a bachelor degree, have satisfactorily completed the honors program in the Department of Engineering Physics and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA≥ 3.5.

Content

The student must

1. Complete at least eight credits of field-approved electives at the 400-level or higher and receive a minimum grade of an A- in each of the courses taken to fulfill this eight-credit requirement. These eight credits are in addition to the credits obtained by completing the senior thesis or special project requirement as discussed in item 2.
2. Enroll in A&EP 490 or an equivalent course over two semesters for the purpose of completing an independent research project or senior thesis under the supervision of a Cornell engineering or science faculty member. The minimum enrollment is to be two credits in the first semester and four credits in the second. The level of work required for a successful completion of this project or thesis is to be consistent with the amount of academic credit granted.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member during the second semester of their junior year. A student must be in the program for at least two semesters before graduation.

Procedures

Before enrolling in A&EP 490, or the equivalent, the honors candidate must submit a brief proposal outlining the topic and scope of the proposed project or thesis and a faculty supervisor's written concurrence to the associate director for undergraduate studies. This proposal will be reviewed by the A&EP Honors Committee and either approved or returned to the candidate to correct deficiencies in the proposal. The proposed research project or senior 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 A&EP Honors Committee. Following the 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. The final research project course grade will be assigned by the faculty supervisor, following the oral presentation and after consultation with the chair of the Honors Committee. A minimum grade of A- is necessary for successful completion of the honors requirement.

Master of Engineering (Engineering Physics) Degree Program

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. A wide latitude is allowed in the choice of the required design project.

One example of a specific area of study is solid-state physics and chemistry as applied to nano-structure science and technology. Core courses in this specialty include the micro-characterization of materials (A&EP 661) and the microprocessing and microfabrication of materials (A&EP 662). The design project may focus on such areas as semiconductor materials, device physics, nanostructure technology, or optoelectronics. Another area of study may be applied optics where core courses can be chosen from applied physics, electrical engineering, and physics.

Each individual program is planned by the student 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. All students granted the degree will have demonstrated competence in an appropriate core of basic physics; if this has not been accomplished at the undergraduate level, subjects such as electricity and magnetism, or classical, quantum, and statistical mechanics should be included in the program.

The general requirement for the degree is a total of 30 credits for graduate-level courses or their equivalent, earned with a grade of C or better and distributed as follows:

1) a design project in applied science or engineering with a written final report (not less than 6 nor more than 12 credits)
2) an integrated program of graduate-level courses, as discussed below (17 to 23 credits)
3) a required special-topics seminar course (one 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 mathematics, statistical mechanics, applied quantum mechanics) and engineering electives (such as 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 are acceptable for credit toward the degree; other undergraduate courses may be required as prerequisites but are not credited toward the degree.

Students interested in the M.Eng. (Engineering Physics) degree program should contact Professor Bruce Kusse.

APPLIED MATHEMATICS

The Center for Applied Mathematics administers a broadly based interdepartmental graduate program that provides opportunities for study and research in a wide range of the mathematical sciences. For detailed information on opportunities for graduate study in applied mathematics, contact the director of the Center for Applied Mathematics, 657 Frank H. T. Rhodes Hall.

There is no special undergraduate degree program in applied mathematics. Undergraduate students interested in application-oriented mathematics may select an appropriate program in the Department of Mathematics or one of the departments in the College of Engineering.

A list of selected graduate courses in applied mathematics may be found in the description of the Center for Applied Mathematics, in the section "Interdisciplinary Centers and Programs."

BIOLOGICAL AND ENVIRONMENTAL ENGINEERING

M. F. Walter, chair; B. A. Ahner, L. D. Albright, D. J. Aneshansley, A. J. Baeumner, J. A. Bartsch, J. R. Cooke, A. K. Datta, K. G. Gebremedhin, D. A. Haith, J. B. Hunter, L. H. Irwin, W. J. Jewell, D. Luo, C. D. Montemagno, J.-Y. Parlange, N. R. Scott, R. M. Spanswick, T. S. Steenhuis, M. B. Timmons, L. P. Walker

Bachelor of Science Curriculum

Biological and Environmental Engineering (BEE) addresses 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 undergraduate engineering program in the Department of Biological and Environmental Engineering 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. The program leads to a bachelor of science degree and is accredited by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET).

Two concentrations in Biological and Environmental Engineering are offered: biological engineering and environmental engineering. Students take courses in mathematics, statistics, computing, physics, chemistry, basic and advanced biology, fundamental engineering sciences (mechanics, thermodynamics, fluid mechanics, and transport processes), engineering applications, and design. Students select upper-level courses in the department in areas that include bioprocessing, soil and water management, biotechnology applications, bioinstrumentation, engineering aspects of animal physiology, environmental systems analysis, and waste treatment and disposal. Students strengthen their programs by selecting additional courses in the College of Engineering. They may complete minors of a second engineering major. Students planning for medical school also take additional lab-based courses in biology, biochemistry and organic chemistry. Throughout the curriculum, emphasis is placed on communications and teamwork skills and all students complete a capstone design project. Many undergraduate students participate in honors programs, undergraduate teaching and research, independent study, assistantships, research assistantships, design teams, Engineering Co-op, and study abroad. Students completing the BEE major should have a strong aptitude for the sciences and mathematics and an interest in the complex social issues that surround technology.

Career opportunities cover the spectrum of private industry, public agencies, educational institutions, and graduate and professional programs in engineering, science, medicine, law, and other fields. In recent years, graduates have developed careers in environmental consulting, biotechnology, the pharmaceutical industry, biomedical engineering, management consulting, 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 and technical people who have studied biology and the environment, 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 Department of Biological and Environmental Engineering is educating the next generation of engineers to meet these challenges.

The Department of Biological and Environmental Engineering is located in Riley-Robb Hall and operates specialized facilities that are among the largest and most complete of their kind in the world. For further details see the department's undergraduate programs publication, available at the BEE Student Service Office, 207 Riley-Robb Hall, or contact the field's advising coordinator, Professor Jim Bartsch, at 255–2800.

The field program requirements for those students joining the program in 2003–2004 are outlined.

Basic Subjects	*Credits*
MATH 191 (or 190), 192, 293, 294 Calculus for Engineers and Engineering Mathematics	16
PHYS 112, 213	8
General Chemistry (207 or 211 or 215)*	4
Organic Chemistry (257 or 357)*	3
Computer Programming	
BEE 151, Introduction to Computing	4
Biological Sciences*	15
Introductory	6–8
Biochemistry	4–5
Advanced Biology	5–2
Engineering Field Courses	
BEE 200, The BEE Experience	1
ENGRD 202, Mechanics of Solids	4
BEE 251 or BEE 260, ENGR Applications	3
BEE 350, Bio & Environ Transport Proc	3
BEE 222, Thermodynamics and Kinetics	3
Engineering Statistics and Probability (ENGRD 270 or CEE 304)	3
Fluid Mechanics (CEE 331 or M&AE 323 or CHEME 323)	3–4
Upper-Level BEE courses (3 courses numbered 450–490; at least one of these must be an approved capstone design course)	9

Technical Engineering Electives (200 level or above; at least one of these must be an approved laboratory experience course)	18–19
Liberal Studies (two freshmen seminars and at least two courses in humanities or history)	24
Approved Electives	6
Total (minimum)	126

*Basic accredited curriculum. Specializations (options or pre-professional study) may be accommodated by selecting additional courses in the indicated area(s). For further information, please contact the BEE Student Services Office, 207 Riley Robb Hall, or contact the undergraduate program director, Professor Jim Bartsch, at jab35@cornell.edu.

Biological and Environmental Engineering Honors Program

Eligibility

The bachelor of science degree with honors will be granted to engineering students who, in addition to having completed the requirements for a bachelor's degree, have satisfactorily completed the honors program in the Department of Biological and Environmental Engineering and have been recommended for the degree by the honors committee of the department. An honor's program student must enter with and maintain a cumulative GPA ≥ 3.5.

Content

A BEE honors program shall consist of at least nine credits beyond the 126 credit minimum required for graduation in BEE. These nine credits shall be drawn from one or more of the following with at least four credit hours of research in the first category:

- A significant research experience or honors project under the direct supervision of a BEE faculty member using BEE 499, Undergraduate Research. A written senior honors thesis must be submitted as part of this component.
- 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 498, Undergraduate Teaching.
- Advanced or graduate courses. These additional courses must be technical in nature, i.e., in engineering, mathematics, biology, chemistry, and physics at the 400+ and graduate level.

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

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member during the second semester of their junior year. A student must be in the program for at least two semesters before graduation.

Procedures

Applications are available in the BEE Student Services office, 207 Riley Robb.

Each applicant to the BEE honors program must have a BEE faculty adviser to supervise the honors program. Written approval of the faculty member who will direct the research is required.

Option in Environmental Engineering

The Environmental Engineering Option provides BEE students the opportunity to follow a structured environmental engineering curriculum. The curriculum was developed and approved jointly by the faculty of BEE and Civil and Environmental Engineering (CEE). The Environmental Engineering Options in BEE and CEE share a common core of courses.

Students complete a prescribed program of courses within the framework of the BEE curriculum.

Chemistry/microbiology: Students must take at least two semesters of chemistry (CHEM 211/257 or CHEM 207/208). They must also satisfy the BEE organic chemistry requirement: either by taking organic chemistry as one of the two required chemistry courses (i.e., CHEM 257) or by taking CEE 451. The microbiology requirement of the Environmental Engineering option can also be met by taking CEE 451.

Chemistry: CHEM 211/257 or CHEM 207/208

Organic chemistry: CHEM 257 or CEE 451

Microbiology: CEE 451 or BIOMI 290

Fluid Mechanics: CEE 331

Probability and Statistics: CEE 304

Environmental Engineering: CEE 351

Environmental Quality Engineering: CEE 453

Laboratory Experience in Environmental Engineering: BEE 473 or 475: Watershed Engineering or Environmental Systems Analysis

Inquiries regarding this option should be addressed to the student's adviser or to Jim Bartsch, undergraduate program director, at jab35@cornell.edu.

Minor in Biological Engineering

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the Biological Engineering minor: A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, MS&E, and OR&IE. (Students may participate in either the Bioengineering Option **or** the Biological Engineering minor, but not both.)

Note: Students should meet with the BEE Program Director as soon as they decide to pursue the minor. Then they will receive a BEE faculty adviser, who will assist them in completing the minor program.

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.

Requirements

To complete the minor, the student must take at least six (6) courses (minimum of 18 credits), which meet the following requirements:

Required course: BEE 350, Biological & Environmental Transport Processes

I. Analysis: Require two (2) from the following courses:

MS&E 304 (3)	Kinetics, Diffusion, and Phase Transformations
CHEME 313 (3)	Chemical Engineering Thermodynamics
CHEME 390 (3)	Reaction Kinetics and Reactor Design
CEE 437 (3)	Experimental Methods in Fluid Dynamics
BEE 685 (4)	Biological Engineering Analysis

II. Application: Require two (2) from the following courses:

BEE 450 (4)	Bioinstrumentation
BEE 453 (3)	Computer-Aided Engineering Applications to Biomedical and Food Processes
BEE 454 (3)	Physiological Engineering
BEE 459 (4)	Biosensors and Bioanalytical Techniques
BEE 655 (3)	Thermodynamics and Its Applications
CHEME 643 (3)	Introduction to Bioprocess Engineering

III. Basic Sciences: One (1) from the following courses:

BIOBM 233 (3)	Introduction to Biomolecular Structure
BIOMI 290 (3)	General Microbiology
BIOBM 330–333 (2–4)	Principles of Biochemistry
BIOBM 434 (3)	Applications of Molecular Biology
BIONB 470 (3)	Biophysical Methods

Academic Standards: A letter grade of C- or better for each course in the minor.

Minor in Environmental Engineering

(Offered in cooperation with the School of Civil and Environmental Engineering)

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the environmental engineering minor: A&EP, CHEME, COM S, EAS, ECE, M&AE, MS&E, OR&IE. 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 use and quality of 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. The requirements for the environmental engineering minor are outlined below. For further details consult the Biological and Environmental Engineering Undergraduate Programs Office, 207 Riley-Robb Hall, or the Civil and Environmental Engineering Undergraduate Programs Office, 221 Hollister Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows.

Students must select courses from the following group listings, with at least one course from each group.

Group A. Environmental Engineering Processes:

CEE 351	Environmental Quality Engineering
CEE 352	Water Supply Engineering
CEE 451	Microbiology for Environmental Engineering
CEE 453	Laboratory Research in Environmental Engineering
BEE 476	Solid Waste Engineering
BEE 478	Ecological Engineering
CEE 644	Environmental Applications of Geotechnical Engineering
BEE 651	Bioremediation
CEE 653	Water Chemistry for Environmental Engineering
CEE 655	Pollutant Transport and Transformation in the Environment
CEE 658	Sludge Treatment, Utilization, and Disposal
CEE 654	Aquatic Chemistry

Group B. Environmental Systems:

ENGRI 113*	Introduction to Environmental Systems (*May count only if taken before the student's junior year.)
BEE 475	Environmental Systems Analysis
CEE 529	Water and Environmental Resources Problems and Policies
CEE 597	Risk Analysis and Management
CEE 623	Environmental Quality Systems Engineering
BEE 678	Nonpoint Source Models

Group C. Hydraulics, Hydrology, and Environmental Fluid Mechanics:

CEE 331	Fluid Mechanics (CHEME 323 or M&AE 323 may be substituted for CEE 331)
CEE 332	Hydraulic Engineering
BEE 371	Hydrology and the Environment
CEE 431/ BEE 471	Geohydrology
CEE 432	Hydrology
CEE 435	Coastal Engineering
CEE 437	Experimental Methods in Fluid Dynamics
BEE 473	Watershed Engineering
BEE 474	Drainage and Irrigation Systems
CEE 633	Flow in Porous Media and Groundwater
CEE 655	Pollutant Transport and Transformation in the Environment
BEE 671	Analysis of the Flow of Water and Chemicals in Soils
BEE 672	Drainage

Academic Standards: A letter grade of C- or better in each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Master of Engineering (Agricultural and Biological) Degree Program

The program for the M.Eng. (Agricultural and Biological) degree is intended primarily for those students who plan to enter engineering practice. The curriculum is planned as an extension of an undergraduate program in biological and environmental engineering but can accommodate graduates of other engineering disciplines. The curriculum consists of 30 credits of courses intended to strengthen the students' fundamental knowledge of engineering and develop their design skills. At least three to nine of the required 30 credits are earned for an engineering design project that culminates in a written and oral report.

The program is designed to be flexible so that the candidate may concentrate in any of a variety of specialty 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, mathematics, biology, and the physical sciences may also be taken as part of a coherent program. Master of Engineering students in Biological and Environmental Engineering 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. More information is available from the BEE Student Services Office, 207 Riley Robb Hall (255–2173), or by e-mail at BEEgradfield@cornell.edu.

CHEMICAL AND BIOMOLECULAR ENGINEERING

P. Clancy, director; K. E. Ackley, A. B. Anton, L. A. Archer, A. M. Center, C. Cohen, M. P. Delisa, T. M. Duncan, J. R. Engstrom, F. A. Escobedo, Y. L. Joo, D. L. Koch, K. H. Lee, W. L. Olbricht, D. Putnam, M. L. Shuler, P. H. Steen, A. D. Stroock

Bachelor of Science Curriculum

The undergraduate field program 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 field program take CHEM 208 during the freshman year. The program for the last three years, for students who have taken an Introduction to Engineering course during the first year, is as follows:

Semester 3	*Credits*
MATH 293, Engineering Mathematics	4
PHYS 213, Electricity and Magnetism	4
CHEM 389, Physical Chemistry I (engineering distribution)	4
ENGRD 219, Mass and Energy Balances (engineering distribution)	3
Humanities or social sciences	3
Semester 4	
MATH 294, Engineering Mathematics	4
CHEM 323, Fluid Mechanics	3
CHEM 290–391, Physical Chemistry (field)	6
Biology elective	3
Humanities or social sciences	3
Semester 5	
CHEM 357, Introductory Organic Chemistry	3
CHEM 251, Organic Chemistry Laboratory	2
CHEME 313, Chemical Engineering Thermodynamics	4
CHEME 324, Heat and Mass Transfer	3
Humanities or social sciences	3
Semester 6	
Advanced Science elective	3
CHEME 301, Nonresident Lectures	1
CHEME 332, Analysis of Separation Processes	3
CHEME 372, Introduction to Process Dynamics and Control	1
CHEME 390, Reaction Kinetics and Reactor Design	3
Humanities or social sciences	3
Semester 7	
CHEME 432, Chemical Engineering Laboratory	4
Electives*	9
Humanities or Social Sciences	3
Semester 8	
CHEME 462, Chemical Process Design	4
Humanities or social sciences	3
Electives*	3
Approved elective	3

*The electives in semester seven and eight comprise six credits of field-approved electives and six credits of advanced CHEME electives. Advanced CHEME electives include any CHEME course at the 400+ level, except CHEME 490, 491, 492, 520, 572, and 601.

Advanced science electives include BIOMI 290, General Microbiology Lectures; BIOBM 330, 331, 332, and 333, Principles of Biochemistry; BMEP (CHEME) 401, Molecular Principles of Biomedical Engineering; BMEP (CHEME) 402, Cellular Principles of Biomedical Engineering; CEE 451, Microbiology for Environmental Engineering; CEE 654, Aquatic Chemistry; CHEME 470, Process Control Strategies; CHEME 480, Chemical Processing of Electronic Materials; CHEME 481, Biomedical Engineering; CHEME 484, Microchemical and Microfluidic Systems; CHEME 640, Polymeric Materials; CHEME 543, Bioprocess Engineering; CHEME 661, Air Pollution Control; FOOD 417, Food Chemistry I; M&AE 423, Intermediate Fluid Dynamics; MS&E 206, Atomic and Molecular Structure of Matter; MS&E 305, Electronic Structure of Matter; MS&E 306, Electrical, Optical, and Magnetic Properties of Materials; MS&E 521, Properties of Solid Polymers; MS&E 531, Introduction to Ceramics; MS&E 541, Microprocessing of Materials; T&AM 310, Advanced Engineering Analysis I; any A&EP course numbered 333 or above; any CHEM course numbered 301 or above; any PHYS course numbered 300 or above.

Master of Engineering (Chemical) Degree Program

The professional master's degree, M.Eng. (Chemical), 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, mathematics, chemistry, physics, and business administration. 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 in the college's introductory section.

Specific requirements include

1) two courses in advanced chemical engineering fundamentals chosen from CHEME 711, 713, 731, 732, and 751
2) two courses in applied chemical engineering science chosen from CHEME 470, 480, 481, 484, 520, 564, 566, 640, 643, 644, 656, and 661
3) a minimum of three credits of a design project, CHEME 565

Dean's certificate programs in Bioengineering, Engineering Management, Energy Engineering, and Manufacturing are available. A program offered jointly with the Food Science Department is also available, leading to both the Master of Engineering and the Master of Professional Studies degrees.

CIVIL AND ENVIRONMENTAL ENGINEERING

J. F. Abel, W. Aquino, L. Banks-Sills, J. J. Bisogni, Jr., W. H. Brutsaert, P. G. Carr, E. A. Cowen, R. A. Davidson, R. I. Dick, L. B. Dworsky, K. Gebremedhin, J. M. Gossett, M. D. Grigoriu, D. A. Haith, K. C. Hover, A. R. Ingraffea, F. H. Kulhawy, L. W. Lion, P. L-F. Liu, D. P. Loucks, J. R. Mbwana, W. McGuire, A. H. Meyburg, L. K. Nozick, P. Petrina, T. D. O'Rourke, K. D. Papoulia, T. Peköz, W. D. Philpot, C. ReVelle, R. E. Richardson, M. J. Sansalone, R. E. Schuler, C. A. Shoemaker, J. R. Stedinger, H. E. Stewart, C. H. Trautmann, M. A. Turnquist, F. Wayno, M. Weber-Shirk, R. N. White

Bachelor of Science Curriculum

The School of Civil and Environmental Engineering (CEE) offers an accredited undergraduate program in civil engineering and permits students to pursue one of two options leading to the B.S. degree: civil engineering or environmental engineering. Within civil engineering, while it is not necessary to do so, students may concentrate in structural engineering, geotechnical engineering, fluid mechanics and hydrology, water resource systems, or transportation. The environmental engineering curriculum emphasizes study of environmental engineering, water resource systems, and fluid mechanics and hydrology. Sample curricula are available in the CEE Undergraduate Program Office, 221 Hollister Hall.

Requirements for Admission to the Field:

Students planning to enter the field program in Civil and Environmental Engineering are required to complete the following courses before or during the first semester of the sophomore year with a grade of C– or better: for the civil option, ENGRD 202, Mechanics of Solids; for the environmental option, either ENGRD 202, Mechanics of Solids or CHEM 208, General Chemistry. In addition, the field requires a cumulative grade point average of at least 2.0 both overall and in engineering and sciences courses.

Recommended Engineering Distribution Courses:

Students in the environmental and civil option are required to take ENGRD 202 (Mechanics of Solids) as an engineering distribution course. The second engineering distribution may be selected according to their interests. For the environmental option the following engineering distribution courses are recommended: ENGRD 201 Introduction to the Physics and Chemistry of the Earth, ENGRD 219 Mass and Energy Balances, ENGRD 221 Thermodynamics, ENGRD 250 Engineering Applications in Biological Systems, BIO G 101 and 103 Biological Sciences Lecture and Laboratory, BIO G 105 Introduction to Biology, BIO G 107 General Biology, or CHEM 389 Physical Chemistry.

Recommended engineering distribution courses for students planning to enter the civil engineering option are:

ENGRD 261, Introduction to Mechanical Properties of Materials, for students interested in structural engineering or civil engineering materials;

ENGRD 201, Introduction to the Physics and Chemistry of the Earth, for students interested in geotechnical engineering;

ENGRD 221, Thermodynamics, for students interested in fluid mechanics and hydraulics/hydrology;

ENGRD 211, Computers and Programming, for students interested in transportation;

ENGRD 241, Engineering Computation,* for all students.

Field Program:

Civil Engineering Option

For the field program in Civil Engineering, students may elect to substitute CHEM 208 for PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum.

Core Courses	*Credits*
ENGRD 203, Dynamics	3
ENGRD 241, Engineering Computation*	3
CEE 304, Uncertainty Analysis in Engineering†	4
CEE 323, Engineering Economics and Management	3
CEE 331, Fluid Mechanics	4
CEE 341, Introduction to Geotechnical Engineering and Analysis	4
CEE 351, Environmental Quality Engineering**	3
CEE 361, Introduction to Transportation Engineering**	3
CEE 371, Modeling of Structural Systems	4

Additional requirements include a set of two field-approved electives and three design electives from an approved list of 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 is taken as an expressive art, then students must take an additional approved elective from a department or school other than Civil and Environmental Engineering.

*ENGRD 241 can be used to satisfy a field program requirement. If a student elects to use this course as a second distribution course, the student must take an additional field-approved elective to fulfill the core course requirements.

†ENGRD 270 may be accepted (by petition) as a substitute for CEE 304 in the field program, but only if ENGRD 270 is taken before entry into the field, or in some special cases where co-op or study abroad programs necessitate such a substitution.

Students may substitute any field-approved elective for either CEE 351 or CEE 361, **if they complete either CEE 376 or CEE 472 and also complete CEE 473. However, this substitute course then counts as a core course only and not as one of the required five CEE Design courses and field-approved electives.

Environmental Engineering Option

These option requirements apply to all students in the Classes of 2002 and later. For the field program in Environmental Engineering, students must take CHEM 208 in place of PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum:

Core Courses	*Credits*
Introductory Biology‡ (BIO G 101 & 103, BIO G 105, or BIO G 107	4
ENGRD 241, Engineering Computation*	3
CEE 304, Uncertainty Analysis in Engineering	4
CEE 323, Engineering Economics and Management	3
CEE 331, Fluid Mechanics	4
CEE 341, Introduction to Geotechnical Engineering and Analysis	4
CEE 351, Environmental Quality Engineering	3
CEE 451, Microbiology for Environmental Engineering§	3
CEE 453, Laboratory Research in Environmental Engineering	3
BEE 475, Environmental Systems Analysis	3

Additional requirements include one‡ field-approved elective and three design electives from an approved list of courses that is available in the CEE Undergraduate Program 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 is taken as an expressive art, then students must take an additional approved elective.

*ENGRD 241 can be used to satisfy a field program requirement. If a student elects to use this course as a second distribution course, the student must take an additional field-approved elective to fulfill the core course requirements.

‡The requirement for students prior to the class of 2002 is two field-approved electives and no requirement for a core course in introductory biology.

§Students planning graduate level study in environmental engineering may take BIOMI 290 Introduction to Microbiology in place of CEE 451. These students should also take CHEM 257 or CHEM 357 Introduction to Organic Chemistry as an approved elective.

Civil and Environmental Engineering Honors Program

Eligibility

The bachelor of science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor's degree, have satisfactorily completed the honors program in Civil and Environmental Engineering and have been recommended for the degree by the faculty of the school. An honors program student must enter with and maintain a cumulative GPA≥ 3.5.

Content

A CEE honors program shall consist of at least nine credits beyond the minimum required for graduation in CEE. These nine credits shall be drawn from one or more of the following components:

1. A significant research experience or honors project under the direct supervision of a CEE faculty member using CEE 400: Senior Honors Thesis (1–6 credits per semester). A significant written report or 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 College of Engineering, i.e., ENGRG 470: Peer Teaching in Engineering or CEE 401: Undergraduate Teaching in CEE (1–3 credits per/semester).
3. Advanced or graduate courses at the 500-level or above.

The minimum number of credits in any component included in a program should be two. No research, independent study, or teaching for which the student is paid may be counted toward the honors program.

Timing

All interested students must apply no later than the beginning of the first semester of their senior year, but are encouraged to apply as early as the first semester of their junior year. All honors program students must be in the program for at least two semesters prior to graduation.

Procedures

Each applicant to the CEE honors program must have a faculty adviser or faculty mentor to supervise the student's individual program. (This need not be the student's faculty adviser.) The application to the program shall be a letter from the student describing the specific proposed honors program and include the explicit approval of the faculty adviser and the honors adviser. 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.

Engineering Minor Programs

The School of Civil and Environmental Engineering currently offers three engineering minor programs: civil infrastructure, engineering management, and environmental engineering (offered in cooperation with the Department of Biological and Environmental Engineering). Descriptions and requirements for each program follow:

Minor in Civil Infrastructure

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the civil infrastructure minor: BEE, A&EP, CHEME, COM S, EAS, ECE, M&AE, MS&E, OR&IE.

The minor in civil infrastructure is intended to introduce engineering 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 which is vital for any modern economy.

The requirements for the civil infrastructure minor are outlined below. For further details consult the Civil and Environmental Engineering Undergraduate Programs Office, 221 Hollister Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. Required Course: ENGRD 202 Mechanics of Solids

II. Additional Courses: choose any 5 (groupings are for information only)*

Geotechnical Engineering

CEE 341 Introduction to Geotechnical Engineering and Analysis

CEE 640 Foundation Engineering

CEE 641 Retaining Structures and Slopes

CEE 644 Environmental Applications of Geotechnical Engineering

Structural Engineering

CEE 371 Modeling of Structural Systems

CEE 376 Physical and Computational Material Simulation

CEE 472 Fundamentals of Structural Mechanics

CEE 473 Civil Infrastructure Design I

CEE 474 Civil Infrastructure Design II

CEE 481 LRFD-Based Engineering of Wood Structures

CEE 672 Fundamentals of Structural Mechanics

CEE 673 Advanced Structural Analysis

Other Related Courses

CEE 332 Hydraulic Engineering

CEE 361 Introduction to Transportation Engineering

CEE 595 Construction Planning and Operations

*Other CEE courses approved by petition in advance.

Academic Standards: A letter grade of C or better for each course in the minor.

Minor in Engineering Management

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the engineering management minor: BEE, A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, MS&E.

This minor focuses on giving engineering 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.

The requirements for the engineering management minor are outlined below. For further details, consult the Civil and Environmental Engineering Undergraduate Programs Offices, 221 Hollister Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. Required Courses (3):

CEE 304 Uncertainty Analysis in Engineering

or ENGRD 270 Basic Engineering Probability and Statistics or ECE 310 Introduction to Probability and Random Signals

CEE 323 Engineering Economics and Management

OR&IE 350 Financial and Managerial Accounting

II. Additional Courses—choose any 3*

CEE 490 Management Practice in Project Engineering

CEE 506 Civil and Environmental Systems

CEE 593 Engineering Management Methods: Data, Information, and Modeling

CEE 594 Economic Methods for Engineering and Management

CEE 595 Construction Planning and Operations

CEE 597 Risk Analysis and Management

CEE 598 Introduction to Decision Analysis

NBA 507 (formerly 401) Entrepreneurship for Scientists and Engineers

or MAE/ENGRG 461 Entrepreneurship for Engineers

or BEE 489 Engineering Entrepreneurship, Management and Ethics

*Other courses approved by petition in advance.

T&AM 310 may not be substituted for CEE 304.

Academic Standards: a letter grade of C or better for each course in the minor.

Minor in Environmental Engineering

(Offered in cooperation with the Department of Biological and Environmental Engineering)

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the environmental engineering minor: A&EP, CHEME, COM S, EAS, ECE, M&AE, MS&E, OR&IE.

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 use and quality of 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.

The requirements for the environmental engineering minor are outlined below. For further details consult the Civil and Environmental Engineering Undergraduate Programs Office, 221 Hollister Hall, or the Biological and Environmental Engineering Undergraduate Programs Office, 207 Riley-Robb Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

Students must select courses from the following group listings, with at least one course from each group.

Group A. Environmental Engineering Processes:

CEE 351 Environmental Quality Engineering

CEE 352 Water Supply Engineering

CEE 451 Microbiology for Environmental Engineering

CEE 453 Laboratory Research in Environmental Engineering

BEE 476 Solid Waste Engineering

BEE 478 Ecological Engineering

CEE 644 Environmental Applications of Geotechnical Engineering

BEE 651 Bioremediation

CEE 653 Water Chemistry for Environmental Engineering

CEE 654 Aquatic Chemistry

CEE 655 Pollutant Transport and Transformation in the Environment

Group B. Environmental Systems:

ENGRI 113/CEE 113* Solving Environmental Problems for Urban Regions (*May count only if taken before the student's junior year.)

BEE 475 Environmental Systems Analysis

CEE 597 Risk Analysis and Management

CEE 623 Environmental Quality Systems Engineering

BEE 678 Nonpoint Source Models

Group C. Hydraulics, Hydrology, and Environmental Fluid Mechanics:

CEE 331 Fluid Mechanics (CHEME 323 or M&AE 323 may be substituted for CEE 331)

CEE 332 Hydraulic Engineering

BEE 371 Hydrology and the Environment

CEE 431/BEE 471 Geohydrology

CEE 432 Hydrology

CEE 436 Case Studies in Environmental Fluid Mechanics

CEE 437 Experimental Methods in Fluid Dynamics

BEE 473 Watershed Engineering

BEE 474 Drainage and Irrigation Systems

CEE 631 Flow and Contaminant Transport Modeling in Groundwater

CEE 633 Flow in Porous Media and Groundwater

CEE 655 Transport, Mixing, and Transformation in the Environment

BEE 671 Analysis of the Flow of Water and Chemicals in Soils

BEE 672 Drainage

Academic Standards: A letter grade of C- or better in each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Master of Engineering (Civil) Degree Program

The M.Eng. (Civil) degree program is a 30-credit (usually 10-course) curriculum designed to prepare students for professional practice. There are two options in this program: one in civil and environmental engineering design and one in engineering management. Both options require a broad-based background in an engineering field. Applicants holding an ABET-accredited (or equivalent) undergraduate degree in engineering automatically satisfy this requirement. Those without such preparation will require course work beyond the graduate program's 30-credit minimum to fulfill the engineering preparation requirement. Both options also require one course in professional (design-option) or managerial (management-option) practice and a two-course project sequence. The project entails synthesis, analysis, decision making, and application of engineering judgment. Normally it is undertaken in cooperation with an outside practitioner, with some options indicating an intensive, full-time session between semesters. The general degree requirements and admissions information are described above in the section entitled "Master of Engineering Degree Programs." Each student's program of study is designed individually in consultation with an academic adviser and then submitted to the school's Professional Degree Committee for approval.

For the M.Eng. (Civil) program in civil and environmental engineering design options, the requirements are:

1) Three courses, one in professional engineering practice (CEE 590) and a two-course design project (CEE 501 and 502).
2) Specialization in a major concentration area—three to five courses in either environmental engineering, environmental fluid mechanics/hydrology, geotechnical engineering, structural engineering, transportation management, or water resources and environmental systems engineering.
3) Technical electives.
4) Study in a related area or areas.

Courses taken as technical electives or in the related subject area(s) may consist of graduate or advanced courses in fields related to the major concentration area, either inside or outside of the school.

For the M.Eng. (Civil) program in the engineering management option, the requirements are:

1) Five courses: Project Management (CEE 590), Engineering Management Methods (CEE 593 and 594), and the Management Project (CEE 591 and 592).
2) One course in finance, accounting, or engineering economics, as appropriate given a student's background.
3) One course in individual and/or organizational behavior from a recommended list.

4) Three courses from a disciplinary or functional specialization, subject to adviser's approval.

The School of Civil and Environmental Engineering cooperates with the the Johnson Graduate School of Management in two joint programs leading to both Master of Engineering and Master of Business Administration degrees. See the introductory section under College of Engineering for details.

COMPUTER SCIENCE

C. Van Loan, chair; B. Arms, G. Bailey, K. Bala, K. Birman, C. Cardie, R. Caruana, T. Coleman, R. L. Constable, A. Demers, R. Elber, D. Fan, J. Gehrke, D. Greenberg, J. Halpern, J. E. Hopcroft, D. Huttenlocher, T. Joachims, J. Kleinberg, D. Kozen, L. Lee, S. Marschner, G. Morrisett, A. Myers, K. Pingali, R. Rugina, F. B. Schneider, D. Schwartz, B. Selman, J. Shanmugasundaram, D. Shmoys, E. G. Sirer, E. Tardos, R. Teitelbaum, S. Vavasis, G. Yona, R. Zabih

Bachelor of Science Curriculum

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.

For the most current and accurate details, visit our web site at www.cs.cornell.edu/ugrad.

The Major

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:

- four semesters of calculus (MATH 191–192–293–294 or 111–122 (or 112)–221–222)
- two semesters of introductory computer programming (COM S 100 and ENGRD 211)
- a one-credit project (COM S 212)
- a seven-course computer science core (COM S 280, 312, 314, 321 or 322 or 421, 381, 414, and 482)
- two 400+ computer science electives, totaling at least six credits
- a computer science project course (COM S 413, 415, 433, 468, 473, 501, 514, 519, or 664)
- a mathematical elective course (ENGRD 270, MATH 300+, T&AM 310, etc.)
- two 300+ courses (field-approved electives) that are technical in nature and total at least six credits
- a three-course specialization in a topic area other than computer science. These courses must be numbered 300-level or greater.

Note: All of the field electives described above must be courses of three or more credit hours, with the exception of the COM S project course, which is two credits or more.

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 adviser, 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

Eligibility

The bachelor of science degree *with honors* will be granted to students who, in addition to having completed the requirements for a bachelor degree, have:

- qualified for *latin* honors in the College of Engineering (basically, a cumulative GPA $\geq$ 3.5)
- at least two courses (3+ credit hours per course) of COM S course work at or above the 500-level (graded courses only; no seminars or two-credit project courses)
- at least six credits of COM S 490 (independent research) spread over two semesters, with a grade of A- or better each term.

See the COM S undergraduate web site for more information on eligibility: www.cs.cornell.edu/ugrad.

Content

Honors courses may not be used to satisfy the COM S 400+ elective requirement, the COM S project requirement, the math elective, or the specialization.

Timing

Honors determinations are made during the senior year. Students wanting to be considered for field honors should notify the Undergraduate Office in the Department of Computer Science via electronic mail at the following address: ugrad@cs.cornell.edu. The subject line for this message should read "HONORS TRACK." Related questions may be addressed to the ugrad e-mail alias, or candidates can call or stop by 303 Upson Hall, 255–0982.

Preparation

Arrangements for doing COM S 490 research should be made directly with faculty members in the department. Students are encouraged to discuss potential contacts with their advisers and/or browse the department's web page at www.cs.cornell.edu for specific leads on research opportunities. The Department of Computer Science reserves the right to make changes to the honors program requirements at any time. Generally speaking, all members of the same graduating class in COM S will be subject to the same honors criteria.

Minor in Computer Science

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the Computer Science minor: A&EP, BEE, CEE, CHEME, EAS, ECE, M&AE, MS&E, and OR&IE.

This minor is for students who anticipate that computer science will play a prominent role in their academic and professional career.

Requirements

To complete the minor, the student must take at least six courses (18 credits minimum) chosen as follows:

I. Required Courses

COM S/ ENGRD 211 Computers and Programming

COM S 321 Numerical Methods in Computational Biology

or COM S/ENGRD 322 Introduction to Scientific Computing

or COM S 421 Numerical Analysis

COM S/ECE 314 Computer Organization

II. Additional Courses

Three COM S courses numbered 280 or higher (excluding seminars and COM S 490). Academic Standards: A letter grade of C or better for each course in the minor.

Note: Computing courses offered by other departments cannot be applied toward the Computer Science minor, with the exception of ECE 314. It is expected that all qualifying courses will be taken at Cornell for a letter grade. No substitutions allowed.

Engineering Minor in Information Science

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the Minor in Information Science: AEP, BEE, CEE, CHEME, COM S, EAS, ECE, M&AE, MSE, and OR&IE.

Information Science is an interdisciplinary field covering 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 of these areas in addition to having a working knowledge of basic probability and statistics necessary for analyzing data occurring in the real world. All courses must be chosen from the course lists below. In addition, a letter grade of C or better is required; S-U courses not allowed.

Requirements

To complete the minor the student must take at least six courses (18 credit minimum) chosen as follows:

- **Statistics**: one course.
- **Information systems** (primarily computer science): two courses.
- **Human-centered systems** (human computer interaction and cognitive science): one course.
- **Social systems** (social, economic, political, cultural, and legal issues): 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 data occurring in the real world.

ENGRD 270 Basic Engineering Probability and Statistics

CEE 304 Uncertainty Analysis in Engineering

ECE 310 Introduction to Probability and Random Signals

Information Systems

COM S 211 Computers and Programming*

CIS 230 Intermediate Web Design*

CIS 330 Applied Databases

LING 424 Computational Linguistics

CIS 430 Information Discovery

CIS 431 Web Information Systems

COM S 432 Introduction to Database Systems

COM S 465 Computer Graphics I

LING 474 Introduction to Natural Language Processing

OR&IE 474 Statistical Data Mining

COM S 478 Machine Learning

OR&IE 480 Information Technology

CIS 501 Software Engineering

ECE 562 Fundamental Information Theory

COM S 574 Language Technologies

COM S 578 Empirical Methods in Machine Learning and Data Mining

*Computer Science majors cannot use CIS 230. COM S 211 cannot be used by majors for which it is a required course, e.g., Computer Science (COM S) and Operations Research and Industrial Engineering (OR&IE)

Human-centered Systems

COGST 101 Introduction to Cognitive Science

PSYCH 205 Perception

PSYCH 214 Cognitive Psychology

COMM 240 Communication and Information Technology

COMM 245 Psychology of Social Computing

PSYCH 280 Introduction to Social Psychology

PSYCH 342 Human Perception: Applications to Computer Graphics, Art, and Visual Display

COMM 345 Human-Computer Interaction Design

PSYCH 347 Psychology of Visual Communications

PSYCH 380 Social Cognition

PSYCH 413 Information Processing: Conscious and Unconscious

PSYCH 416 Modeling Perception and Cognition

COMM 440 Advanced Human-Computer Interaction Design

COMM 450 Language and Technology

COM S 465 Computer Graphics I

Social Systems

S&TS 250 Technology in Society

S&TS 292 Inventing an Information Society

ECON 301 Microeconomics*

ECON 313 Intermediate Microeconomic Theory*

SOC 304 Social Networks and Social Processes

STS 349 Media Technologies

S&TS 355 Computers: From Babbage to Gates

S&TS 387 The Automatic Lifestyle: Consumer Culture and Technology

LAW 410 Limits on and Protection of Creative Expression—Copyright Law and Its Close Neighbors

S&TS 411 Knowledge, Technology, and Property

ECON 419 Economic Decisions Under Uncertainty

COMM 428 Communication Law

OR&IE 435 Introduction to Game Theory*

STS 438 Minds, Machines, and Intelligence

ECON 467 Game Theory*

ECON 476/576 Decision Theory I and II

*Only one of ECON 301 and ECON 313 can be taken for IS credit. Only one of OR&IE 435 and ECON 467 can be taken for IS credit.

Master of Engineering (Computer Science) Degree Program

The M.Eng. program in computer science is a one-year program that 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 in computer science includes several upper-division and graduate courses and a faculty-supervised project. The course and project requirements are flexible and allow students to build up a program that closely matches their interests. In particular, slightly under half the courses may be taken outside the computer science department (for example, 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 at least one credit and no more than eight 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.

For more information about the M.Eng. program in computer science and the early admission option for Cornell seniors, please consult our web page at www.cs.cornell.edu/grad/meng.

Cooperative Program with the Johnson Graduate School of Management

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. This program, which is sponsored jointly by the College of Engineering and the Johnson Graduate School of Management, enables students to study several subjects required for the M.B.A. degree as part of their undergraduate curriculum. Planning must begin early, however, if all requirements are to be completed on schedule.

For further details and assistance in planning a curriculum, students can consult with their adviser, the undergraduate office in 303 Upson Hall, or the Johnson School directly.

EARTH AND ATMOSPHERIC SCIENCES

T. E. Jordan, chair; S. J. Riha, co-chair; Directors of Undergraduate Studies: K. H. Cook (Science of Earth Systems), R. W. Kay (Geological Sciences), and S. J. Colucci (Atmospheric Science); R. W. Allmendinger, W. D. Allmon, M. Barazangi, J. M. Bird, L. D. Brown, L. M. Cathles, J. L. Cisne, A. T. DeGaetano, L. A. Derry, P. J. Gierasch, C. H. Greene, D. L. Hysell, B. L. Isacks, S. Mahlburg Kay, M. C. Kelley, F. H. T. Rhodes, W. M. White, D. S. Wilks, M. W. Wysocki

Bachelor of Science Curriculum

We live on a planet with finite resources and a finite capacity to recover quickly from human-induced environmental stresses. It is also a powerful planet, with geologic hazards such as earthquakes, hurricanes, and volcanic eruptions that alter the course of history with little prior warning. As the human population grows, understanding the earth and its resources becomes progressively more important for both future policymakers and ordinary citizens. Because the human need to understand the earth is so pervasive, we provide our students with three tracks covering the spectrum of modern earth sciences.

The Department of Earth and Atmospheric Sciences offers an undergraduate engineering program which permits students to pursue one of three options leading to a B.S. degree in geological sciences: the geoscience option, the atmospheric science option, and the science of earth systems (SES) option. The geoscience option emphasizes the structure, composition, and evolution of our planet; the atmospheric science option covers the planetary processes producing weather and climate; and the SES option is concerned with processes on and near the earth's surface where the interactions of water, life, rock, and air produce our planetary environment. An engineering minor is available in one or a combination of these programs.

Atmospheric Science Option

Atmospheric science is the study of the atmosphere and the processes that shape weather and climate. The curriculum emphasizes the scientific study of the behavior of weather and climate, and applications to the important practical problems of weather forecasting and climate prediction. Students develop a fundamental understanding of atmospheric processes, and acquire skill and experience in the analysis, interpretation, and forecasting of meteorological events. The atmospheric science option satisfies both the curricular guidelines of the American Meteorological Society and the educational requirements of the National Weather Service for employment as a meteorologist, which also qualifies graduates for positions in private-sector forecasting and environmental consulting firms. The option also provides excellent preparation for graduate work in atmospheric science and related fields.

Students following the atmospheric science option are required to take ENGRD 270 as an engineering distribution course. The field program includes required introductory courses in atmospheric science (EAS 131 and 133) and EAS 250 (Instrumentation and Observations). Many of the upper division field courses require EAS 341 (Atmospheric Thermodynamics and Hydrostatics) and EAS 342 (Atmospheric Dynamics) as prerequisites, which are normally taken in the junior year. The additional required field program courses are EAS 331 (Climate Dynamics), EAS 352 (Synoptic Meteorology I), EAS 451 (Synoptic Meteorology II), EAS 435 (Statistical Methods in Meteorology), and EAS 447 (Physical Meteorology). Field-approved electives may be chosen from other EAS courses or from selected upper-division courses offered in other departments.

Geoscience Option

The geoscience option reveals Earth's turbulent history from the formation of our solar system to the plate tectonic cycles that dominate Earth's present behavior. That history is highlighted by the co-evolution of life and the Earth system—from the origin of life to the modern inter-glacial phase during which our species has so proliferated. Topics of study also include the fundamental processes responsible for earthquakes, volcanic eruptions, and mountain building. The geoscience option prepares students for advanced study in geology, geophysics, geochemistry, and geobiology, and careers in mineral and petroleum exploration or in environmental geology. Alternatively, it is a valuable major for a pre-law or pre-med program or in preparation for a career in K–12 education.

The geoscience option stresses a balanced overview of geology with considerable flexibility and a degree of specialization achieved by careful selection of field-approved electives. Students are required to take ENGRD/EAS 201 as an engineering distribution course. For students interested in geobiology or paleontology, BIO G 101/103–102/104 (or BIO G 109–110) are recommended. CHEM 208 may be substituted for PHYS 214.

The geoscience option requires the following courses: the introductory outdoor field course, EAS 210, and the five core courses, EAS 326, 355, 356, 375, and 388. Two additional EAS field-required courses and at least one field-approved elective must be EAS 300 through 600-level courses. The core courses may be taken in any reasonable sequence, except that EAS 355, which is offered in the fall, should be taken before EAS 356, which is offered in the spring. EAS 326, 355, 356, and 375 should be taken relatively early in the major program.

In addition, a requirement for an advanced outdoor field experience may be met by completing one of the following four-credit options: (a) EAS 417 (Field Mapping in Argentina, 3 credits) and EAS 491–492 (based on field observations) for a combined four-credit minimum; (b) EAS 437 (Geophysical Field Methods, 3 credits) plus at least one credit of EAS 491 or 492 using geophysical techniques from EAS 437; (c) EAS 491–492 (Undergraduate Research, two credits each) with a significant component of field work; or (d) an approved outdoor field course taught by another college or university (four-credit minimum).

A selection of field-approved electives may provide specializations in geophysics, geochemistry (including petrology and mineralogy), geobiology (paleontology), and geology applied to mineral and petroleum industries, environmental problems, hydrology, and civil engineering. Students intending to specialize in economic geology or pursue careers in the mining industries or mineral exploration should consider including economics courses among their liberal studies distribution courses. Students who want a more general background or want to remain uncommitted with regard to specialty must choose at least two of their field-approved electives from the same field. The field-approved electives outside the field may be chosen from offerings in other science or engineering fields or the liberal arts, but should be at the 300 level or above. Students may request substitution of EAS 491 and 492, Undergraduate Research, for a fourth-year field-approved elective but not if it is being used to fulfill the outdoor field requirement.

In addition to course work, students learn by involvement in research projects. Facilities include equipment for processing seismic signals and digital images of the Earth's surface, instruments for highly precise isotope and element analyses, and extensive libraries of earthquake records, satellite images, and exploration seismic records. High-pressure, high-temperature mineral physics research uses the diamond anvil cell and the Cornell High Energy Synchrotron Source (CHESS). Undergraduates have served as field assistants for faculty members and graduate students in Argentina, British Columbia, the Aleutian Islands, Scotland, Switzerland, Tibet, and Barbados. Undergraduates are encouraged to participate in research activities, frequently as paid assistants.

Science of Earth Systems (SES) Option

The Science of Earth Systems (SES) option provides an integrated view of Earth processes critical to the understanding of our environment. This scientific understanding is the primary foundation used to determine to what degree human societies can modify or adapt to future change. The SES option is for students interested in careers and/or graduate study in any of the Earth system sciences or a future in environmental law, environmental engineering, science teaching, or environmental public policy. The SES option enables students in the College of Engineering to take part in the multidisciplinary, intercollege program in the Science of Earth Systems. Collaborations with other departments provide breadth and depth to the program.

The SES option emphasizes a strong preparation in basic mathematics and sciences and an integrated approach to the study of the Earth system including the lithosphere, biosphere, hydrosphere, and atmosphere.

Students are required to take a second semester of chemistry, two semesters of introductory biology, and ENGRD 201 (Physics and Chemistry of the Earth) as one of the engineering distribution courses. The option requires a set of three core courses, normally taken in the junior or senior years, which provide breadth and integration. An additional set of five intermediate to advanced courses are selected to provide depth and a degree of specialization. These courses permit the student to specialize in such areas as climate dynamics, biogeochemistry, ocean sciences, environmental geosciences, ecological systems, hydrological sciences, and soil sciences.

The field requirements for the SES option are summarized as follows. CHEM 208 and ENGRD 201/EAS 201 are required. The field program includes BIO G 101/103–102/104 (or BIO G 109–110), BIOEE 261, the three SES core courses listed below, five additional courses selected with the adviser's approval to provide specialization in one or a combination of the areas covered by SES, and an additional field-approved elective. Two of the specialization courses will count as field-required courses, and three as field-approved electives. At least three of the field-approved electives must be non-EAS courses. The three SES core courses are:

EAS 302 Evolution of the Earth System—Spring. 4 credits

EAS 321 Biogeochemistry (also NTRES 321)—Fall. 4 credits

EAS 331 Climate Dynamics (also ASTRO 331)—Fall. 4 credits

Areas of specialization include (but are not limited to) the following:

- Biogeochemistry
- Climate dynamics
- Ecological systems
- Environmental biophysics
- Environmental geology
- Hydrological sciences
- Soil science
- Ocean sciences

In addition to faculty in or associated with the Department of Earth and Atmospheric Sciences, faculty currently associated with the SES program include the following: W. Brutsaert (CEE); R. Howarth (EEB); J.-Y. Parlange (BEE); J. Yavitt (NTRES).

Earth and Atmospheric Science Honors Program

Eligibility

The bachelor of science degree (in geological sciences) with honors will be granted to students who, in addition to having completed the requirements for a bachelor's degree, have satisfactorily completed the honors program in Earth and Atmospheric Sciences and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA ≥ 3.5.

Content

In addition to the minimum requirements, a student must

1. take at least nine credits above the minimum required for graduating and approved by the upperclass adviser;
2. have a written proposal of the honors project accepted by his or her faculty adviser and the director of undergraduate studies;
3. complete an honors thesis involving research (EAS 491–492 or 499, two or more credits each) of breadth, depth, and quality.

Timing

A student interested in completing an honors thesis must, by the beginning of the seventh semester, have a written proposal of the honors project accepted by the student's adviser and the director of undergraduate studies.

Procedures

Each applicant to the Earth and Atmospheric Sciences honors program must have a faculty adviser to supervise the honors thesis research. Written approval by the faculty member who will direct the research is required. After the college verifies the student's grade-point average, the student will be officially enrolled in the honors program.

Minor in Geological Sciences

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the Geological Sciences minor: BEE, A&EP, CEE, CHEME, COM S, ECE, M&AE, MS&E, OR&IE.

Whereas many engineering students will encounter and have to understand the natural operating systems of Earth in their professions, the tools and techniques used by Earth scientists to understand these solid and fluid systems over the widest scales of space and time are of use to a wide cross-section of engineering students. This minor is designed to give a flexible set of options for students looking to complement training in their major field with a core education in Geological Sciences.

The requirements for the Geological Sciences minor are outlined below. For further details consult the Undergraduate Programs Office, 2122 Snee Hall, or www.eas.cornell.edu.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. Choose one or both of these courses:

   ENGRD 201 Introduction to the Physics and Chemistry of the Earth

   EAS 210 Introduction to Field Methods in Geological Sciences

II. Choose at least two courses from the following list of core courses:

   EAS 302 Evolution of the Earth System

   EAS 321 Introduction to Biogeochemistry

   EAS 326 Structural Geology

   EAS 355 Mineralogy

   EAS 356 Petrology and Geochemistry

   EAS 375 Sedimentology and Stratigraphy

   EAS 388 Geophysics and Geotectonics

III. To complete the minor, these three to four courses are to be supplemented with two to three additional EAS courses at the 300 level or higher. These may include, for example, additional courses from the above list of core courses, undergraduate research courses, and outdoor field courses.

Academic Standards: A letter grade of C- or better for each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

ELECTRICAL AND COMPUTER ENGINEERING

C. R. Pollock, director; C. E. Seyler, associate director; S. B. Wicker, associate director; A. B. Apsel, J. M. Ballantyne, T. Berger, A. W. Bojanczyk, M. Burtscher, H.-D. Chiang, D. F. Delchamps, L. F. Eastman, D. T. Farley, T. L. Fine, W. K. Fuchs, Z. Haas, D. A. Hammer, M. Heinrich, S. S. Hemami, C. R. Johnson, Jr., E. Kan, M. C. Kelley, P. M. Kintner, R. Kline, K. T. Kornegay, A. Lal, M. Lipson, R. Manohar, J. F. Martínez, S. A. McKee, B. A. Minch, T. W. Parks, F. Rana, A. P. Reeves, A. Scaglione, S. Servetto, J. R. Shealy, E. Speight, M. G. Spencer, C. L. Tang, R. J. Thomas, J. S. Thorp, S. Tiwari, L. Tong

Bachelor of Science Curriculum

The Department of Electrical and Computer Engineering offers an undergraduate field program which leads to a B.S. degree in electrical and computer engineering. The curriculum provides a foundation which reflects the broad scope of this engineering discipline.

Concentrations include computer engineering and digital systems; control systems; electronic circuit design; information, communication, and decision theory; microwave electronics; plasma physics; power and energy systems; quantum and optical electronics; radio and atmospheric and space physics; and semiconductor devices and applications.

Electrical and Computer Engineering Field Program

Students planning to enter the field program in Electrical and Computer Engineering must take ENGRD 230 as an engineering distribution course. The fall of the sophomore year is the preferred term for ENGRD 230 for students without advanced standing in mathematics. Electrical and Computer Engineering students with an interest in computer engineering are encouraged to take ENGRD 211 as an engineering distribution course prior to entry into the field program. In addition, the field program normally begins in the spring of the sophomore year, as shown below. All of these courses (except ECE 210 and ENGRD 230) are taught only once each academic year, either spring or fall, as indicated in the course descriptions.

Course	Credits
Field-Required Courses	
ECE/ENGRD 210, Introduction to Circuits for Electrical and Computer Engineers	4
ENGRD 230, Introduction to Digital Logic Design	4
ECE 301, Signals and System I	4
ECE 303, Electromagnetic Fields and Waves	4
ECE/COM S 314, Computer Organization	4
ECE 315, Introduction to Microelectronics	4
Field-Approved Electives (32-credit minimum in the following categories)	
Advanced ECE Electives†	(7 lecture courses)
Outside ECE Electives‡	9 minimum credits
Total minimum field credits	52

ECE 310 can be taken in place of ENGRD 270 or T&AM 310 to satisfy the college application of probability and statistics requirement.

†These electives must include two 400 level electrical and computer engineering culminating design experience (CDE) courses and at least two additional courses at the 400-level or above. The remaining electives may not include independent project courses, such as ECE 391, 392, 491, or 492, and must be at the 300 level or above in Electrical and Computer Engineering.

Courses that meet the CDE requirement are described in the online *ECE Handbook*. (The list is dynamic and changes frequently. Always refer to the latest information in the *ECE Web Handbook*.) All courses must have a college-level prerequisite.

‡Must include one course at the 300 level or above (see *Electrical and Computer Engineering Web Handbook* for details).

All students graduating with a B.S. degree must fulfill the engineering design requirement and the college technical writing requirement. Two culminating design experience (CDE) courses (4 credits each) satisfy the engineering design requirement. The technical writing requirement is discussed in the College of Engineering section of this book.

Undergraduate specialization is achieved through the various electrical and computer engineering elective courses, as well as other courses in related technical fields within engineering, mathematics, 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.

An electrical and computer engineering honors program also exists for those students who apply between their fifth and sixth semester and meet the program entrance requirements. The honors program requires an additional senior ECE course; a required senior year honors project, at the appropriate level, with an ECE faculty member, and completion of the honors seminar in the junior year. Details are available via the electrical and computer engineering homepage located through the web at www.ece.cornell.edu/students/progugrad.shtml/#guide.

All students majoring in electrical and computer engineering are expected to meet the following academic standards:

1. Students must achieve a grade-point average of at least 2.3 every semester.
2. No course with a grade of less than C– may be used to satisfy degree requirements in the field program or serve as a prerequisite for a subsequent electrical and computer engineering course.
3. Students must complete satisfactorily ECE 210, MATH 294, and PHYS 214 by the end of the sophomore year in the field program of Electrical and Computer Engineering, and make adequate progress toward the degree in subsequent semesters.
4. Honors program students must meet the GPA and progress requirements specified in the *Electrical and Computer Engineering Web Handbook* and the college handbook to remain active participants.

Electrical and Computer Engineering Honors Program

Eligibility, Entry, and Continuation

A student must apply to enter the ECE Honors Program and may do so as early as the beginning of the fifth semester or as late as the end of the sixth semester. A student must have a cumulative GPA of at least 3.5 to apply for entry. A student in the honors program whose cumulative GPA falls below 3.5 at the end of any semester will be dropped from the honors program by College of Engineering regulations. There is an additional requirement (see Honors Seminar) for entry into the program after the end of the fifth semester.

Honors Seminar

Any student in the honors program is required to take (or to have taken) an honors seminar during his or her junior year. The Honors Seminar is a two-credit course (offered spring only) consisting of a weekly series of introductory research lectures by Electrical and Computer Engineering faculty members. Each Honors Seminar enrollee will be required to write two short papers on topics covered in the lecture series. Many Electrical and Computer Engineering faculty members will give a lecture or short series of lectures as part of the Honors Seminar. Students in the honors program and students with a cumulative GPA of at least 3.5 who are considering entering the honors program must receive letter grades for the Honors Seminar.

Honors Project

Any student in the honors program is required to accumulate at least three credit hours from a senior year honors project with an ECE faculty member, consisting either of design, or directed reading. 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

Any student in the honors program is required to take at least three credit hours 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 field program.

The program described above requires honors program participants to amass at least nine credit hours over and above the 128 credit hours required for a B.S. degree; thus an honors degree requires a minimum of 137 credit hours.

Minor in Electrical and Computer Engineering

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the Electrical and Computer Engineering minor: BEE, A&EP, CEE, CHEME, COM S, EAS, M&AE, MS&E*, OR&IE. (*MS&E students planning to pursue this minor must receive prior written approval from both MS&E and ECE, via petition.)

The School of Electrical and Computer Engineering offers a minor to students who wish to complement their major field by obtaining a background in electrical and computer engineering. The minor offers the opportunity to study analog and digital circuits, signals and systems, electromagnetic fields, and additionally specialize at higher levels in one of several different areas such as circuit design, electronic devices, communications, computer engineering, networks, or space engineering.

The requirements for the Electrical and Computer Engineering minor are outlined below. For further details consult the Electrical and Computer Engineering Undergraduate Programs Office, 222 Phillips Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. Required Courses:

ECE/ENGRD 210 Introduction to Circuits for Electrical and Computer Engineers (4 credits)

ENGRD 230 Introduction to Digital Logic Design

II. Two of the following:

ECE 301 Signals and Systems I

ECE 303 Electromagnetic Fields and Waves

ECE/CS 314 Computer Organization

ECE 315 Introduction to Microelectronics

III. One other ECE course at the 300 level or above (3 credit minimum)

IV. One other ECE course at the 400 level or above (3 credit minimum)

Academic Standards: A letter grade of C- or better for each course to be counted in the minor and a cumulative GPA of 2.3 or better for all courses in the minor.

Master of Engineering (Electrical) Degree Program

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 a minimum of four courses in electrical and computer engineering. An electrical and computer engineering design project is also required and may account for three to eight credits of the M.Eng. program. Occasionally, students take part in very extensive projects and may apply for a waiver of the eight-credit maximum and 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, mathematics, or the physical sciences.

Cornell undergraduate students with advanced standing frequently take one or more graduate-level courses prior to graduation and may actually begin accumulating credit toward the Master of Electrical and Computer Engineering program in their last semester of undergraduate work. Application of credits taken while an undergraduate at Cornell must be approved in advance of the last semester of undergraduate work.

Although admission to the M.Eng. (Electrical) program is highly competitive, all well-qualified students are urged to apply. Further information is available from the Master of Electrical and Computer Engineering Program web site at www.ece.cornell.edu/students/progmeng.shtml.

MATERIALS SCIENCE AND ENGINEERING

C. K. Ober, director, D. G. Ast, S. P. Baker, J. M. Blakely, R. Dieckmann, E. P. Giannelis, D. T. Grubb, G. G. Malliaras, A. L. Ruoff, S. L. Sass, C. C. Umbach, R. B. van Dover, M. O. Thompson, U. B. Wiesner

Bachelor of Science Curriculum

Students majoring in materials science and engineering are required to take ENGRD 261 or ENGRD 262 before affiliating with the field. It is strongly recommended that these courses be taken as engineering distribution during the sophomore year. The field program develops a comprehensive understanding of the physics and chemistry underlying the unique properties of modern engineering materials and processes.

In the field, students are required to complete a series of electives to develop knowledge of materials, such as biomaterials, ceramics, polymers, and semiconductors. Application-related courses include the 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, selected from multiple 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. For course details and additional information, see the MS&E web site at www.mse.cornell.edu.

The requirements of a Bachelor of Science degree in materials science and engineering are:

1) Completion of the common engineering curriculum including liberal studies electives
2) ENGRD 261, Mechanical Properties of Materials: From Nanodevices to Superstructures OR

   ENGRD 262, Electronic Materials for the Information Age
3) Completion of 12 required field courses:

   MS&E 204 Materials Chemistry

   MS&E 206 Atomic and Molecular Structure of Matter

   MS&E 302 Mechanical Properties of Materials, Processing, and Design

   MS&E 303 Thermodynamics of Condensed Systems

   MS&E 304 Kinetics, Diffusion, and Phase Transformations

   MS&E 305 Electronic, Magnetic, and Dielectric Properties of Materials

   MS&E 307 Materials Design Concepts I

   MS&E 311 Junior Lab I

   MS&E 312 Junior Lab II

   MS&E 403/405 Senior Materials Lab I or Senior Thesis I

   MS&E 404/406 Senior Materials Lab II or Senior Thesis II

   MS&E 407 Materials Design Concepts II
4) Two materials-related electives covering two groups of different materials
5) Three application-related electives in at least two different types of applications
6) Two applications-related electives must be taken from outside MS&E
7) One additional technical elective outside of MS&E

The department's course curriculum consists of ENGRD 261 or ENGRD 262, the 12 required field courses, and the five technical electives constituting the materials and application-related requirements.

Materials Science and Engineering Honors Program

Eligibility

The bachelor of science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor's degree, have satisfactorily completed the honors program in materials science and engineering and have been recommended for the degree by the honors committee of the department. An honors program student must enter with, and maintain, a cumulative GPA above 3.5.

Content

The requirements for an honors degree in materials science and engineering are:

1. Students must complete at least nine credits beyond the minimum required for graduation in materials science and engineering. This increases the minimum number of credits for graduation with honors to 140. These additional courses must be technical in nature, i.e., in engineering, mathematics, chemistry, and physics at the 400- and graduate-level, with selected courses at the 300-level. All courses satisfying this requirement must be approved by the upper class adviser.
2. Senior honors thesis (MS&E 405/406) with a grade of at least A.

Note: Undergraduates typically enter the honors program at the beginning of their senior year (seventh semester) and thus must have a cumulative GPA equal to or greater than 3.5 at that point.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member to work on a senior honors thesis during the second semester of their junior year. A student must be in the program for at least two semesters prior to graduation.

Procedures

Each application to the materials science and engineering honors program must have a faculty adviser to supervise the honors program. Written approval of the faculty member who will direct the research is required. After the student's grade-point average is verified, the student will be officially enrolled in the honors program.

Minor in Materials Science and Engineering

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the materials science and engineering minor: BEE, A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, OR&IE.

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

The requirements for the materials science and engineering minor are outlined below. For further details, consult the Materials Science and Engineering Undergraduate Program Office, 214 Bard Hall.

Requirements

To complete the minor, students must take at least six courses (minimum of 18 credits), chosen as follows:

1. ENGRD 261 Mechanical Properties of Materials: From Nanodevices to Superstructures OR ENGRD 262, Electronic Materials for the Information Age
2. Two of:

   MS&E 204 Materials Chemistry

   MS&E 206 Atomic and Molecular Structure of Matter

   MS&E 302 Mechanical Properties of Materials, Processing, and Design

   MS&E 303 Thermodynamics of Condensed Systems

   MS&E 304 Kinetics, Diffusion, and Phase Transformations

   MS&E 305 Electronic, Magnetic, and Dielectric Properties of Materials
3. Three electives chosen from:

Any MS&E course at the 300 level or above.

Selected courses in materials properties and processing (at the 300 level or above) from A&EP, CHEME, CEE, ECE, M&AE, PHYS, and CHEM, as approved by the MS&E undergraduate coordinator.

Academic Standards: A letter grade of C or better for each course in the minor.

Master of Engineering (Materials) Degree Program

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) program. This program consists of 30 credits, including 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 MS&E. One three-credit technical elective must include advanced mathematics (modeling, computer application, or computer modeling), beyond the MS&E undergraduate requirements.

MECHANICAL AND AEROSPACE ENGINEERING

S. Leibovich, director; 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, R. D'Andrea, P. R. Dawson, P. C. T. deBoer, E. M. Fisher, E. Garcia, A. R. George, F. C. Gouldin, C. Hui, H. Lipson, M. Y. Louge, J. L. Lumley, M. P. Miller, F. C. Moon, F. K. Moore, S. Mukherjee, R. M. Phelan, S. L. Phoenix, S. B. Pope, M. L. Psiaki, E. L. Resler, Jr., A. Ruina, W. Sachse, S.E. Shen, 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

Members of the faculty of the graduate fields of Aerospace Engineering and Mechanical Engineering are listed in the *Announcement of the Graduate School.*

Bachelor of Science Curriculum in Mechanical Engineering

The upperclass field program in Mechanical Engineering is designed to provide a broad background in the fundamentals of this discipline as well as to offer an introduction to the many professional and technical areas with which mechanical engineers are concerned. The program covers both major streams of the field of mechanical engineering.

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

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

The undergraduate program is a coordinated sequence of courses beginning in the sophomore year. During the fall term sophomore students who plan to enter the Mechanical Engineering program take ENGRD 202 (also T&AM 202) as an engineering distribution course. They also are encouraged to take ENGRD 221 (also M&AE 221), which is a field requirement that may simultaneously satisfy Common Curriculum requirements as an engineering distribution course. Occasionally because of study abroad or requirements for second majors or pre-med, students cannot complete all of the required sophomore courses on schedule. In such cases students should delay ENGRD 221 until the first semester of the junior year. The Sibley School supports students with unusual requirements, but any delays or substitutions must be discussed with and receive approval from the student's advisor.

The course requirements for the degree of bachelor of science in Mechanical Engineering are as follows:

1. Completion of the Common Curriculum. During the upperclass years this will typically mean earning credit for five humanities or social science courses.
2. Completion of the field requirements, which consist of eleven required courses (beyond ENGRD 202 already mentioned), and five field-approved elective courses.

   The eleven required courses are:

   M&AE 212, Mechanical Properties and Selection of Engineering Materials

   M&AE 221, Thermodynamics

   M&AE 225, Mechanical Design and Synthesis

   T&AM 203, Dynamics

   ECE 210, Introduction to Circuits for Electrical and Computer Engineers

   M&AE 323, Introductory Fluid Mechanics

   M&AE 324, Heat Transfer

   M&AE 325, Mechanical Design and Analysis

   M&AE 326, System Dynamics

   M&AE 427, Fluids/Heat Transfer Laboratory

   M&AE 428, Engineering Design

Electives

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

Field Approved Electives

The upper-level program includes five field-approved electives. Using these five courses, the student must satisfy the following requirements.

At least three of the courses must be upper-level (300+) M&AE courses. Of these three, two must satisfy a concentration chosen by the student. Typically these are two courses chosen from an appropriate subset of the school's upper-class offering. However, students may petition for approval of two related courses to form a custom concentration.

The standard concentrations are:

Fluids/Aerospace Engineering, M&AE 305, 306, 415, 423, 506, 507

Thermal Systems Engineering, M&AE 423, 449, 453, 501, 506, 543

Materials Processing, M&AE 412, 415, 514

Mechanical Systems, M&AE 412, 417, 470, 478, 479, 525, 565

Vehicle Engineering, M&AE, 306, 386, 425, 426, 440, 441, 449, 486, 506, 507

Biomechanics, M&AE 463, 464, 565

Of the three upper-level M&AE courses, one must be an approved design elective. The design offerings may change from year to year.

Typically this list includes M&AE 401, 412, 426, 441, 470, 479, 486, 491, and 525.

Note that the design elective must be taken during the senior year. Note that a single course may satisfy both the design and concentration requirements, in which case the third course could be any upper-level M&AE course.

One of the courses must be an approved upper-level mathematics course taken after MATH 294. The course must include some material on statistics. Currently, the approved courses are T&AM 310, OR&IE 270, and CEE 304.

One of the field-approved electives can be viewed as a technical elective and may be any course at an appropriate level, chosen from engineering, mathematics, or science (physics, chemistry, or biological sciences). Appropriate level is interpreted as being at a level beyond the required courses of the college curriculum. Note that courses in economics, business, and organizational behavior are not accepted. Advisors may approve such courses as approved electives.

Approved Electives

To maximize flexibility (i.e., the option for study abroad, COOP, internships, pre-med, and flexibility during the upper-class years), the Sibley School faculty recommends that students delay use of approved electives until after term three. The faculty encourages students to consider the following as possible approved electives:

- any 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 informational 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 (economics, financial, legal, etc.)
- courses in organizational behavior
- courses in cognitive sciences.

The faculty recommendation on humanities/ social sciences electives is that students build a program that includes studies in:

- history of technology
- societal impacts of technology
- history
- foreign languages
- ethics
- communications
- political science
- aesthetics
- economics
- architecture

An additional graduation requirement of the field program is proof of elementary competence in computer-aided design and technical drawing for students affiliating in spring 2003 or later. The demonstration of competence is expected to take place in M&AE 225, Mechanical Synthesis. This proof may also be given in other ways, for example:

a. A course with computer-aided design with technical drawing in high school or in a community college,

b. another computer-aided design and technical drawing course at Cornell, or

c. a departmental examination.

The technical writing requirement of the Common Curriculum is satisfied by M&AE 427.

Introduction to Circuits for Electrical and Computer Engineers (ECE 210) may be replaced or supplemented by Electronic Circuits (PHYS 360).

A limited set of third-year courses is offered each summer under the auspices of the Engineering Cooperative Program.

More detailed materials describing the Mechanical Engineering Program can be obtained from the Sibley School of Mechanical and Aerospace Engineering, Upson Hall.

Minor in Mechanical Engineering

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the mechanical engineering minor: BEE, A&EP, CHEME, CEE, COM S, EAS, ECE, MS&E, OR&IE.

Requirements

To complete the minor, the student must choose at least six courses (minimum of 18 credits) from among the following: M&AE courses at the 200 level or above; ENGRD 202, Mechanics of Solids; ENGRD 203, 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 300.

  b) At least one course must be either (1) numbered above 500 or (2) numbered above 326 and have as its prerequisite ENGRD 202, ENGRD 203, or an M&AE course.

  c) Each course must be worth at least three credits.

(2) Substitutions of courses other than M&AE (or ENGRD 202 and 203) will not be accepted as part of the M&AE minor. However, some instructors of M&AE courses will accept non-M&AE courses as substitute prerequisites for their courses, or may choose to waive prerequisites in some circumstances. Students should check with the course instructor.

Academic Standards: A letter grade of C- or better for each course in the minor.

Examples of typical minor programs are as follows:

Typical focus in Fluids/Thermal Systems:

The following four courses:

ENGRD 202 Mechanics of Solids

ENGRD 203 Dynamics

ENGRD 221 Thermodynamics

M&AE 323 Introductory Fluid Mechanics

Plus two of the following, of which at least one course must satisfy requirement 1b:

M&AE 305 Introduction to Aeronautics

M&AE 324 Heat Transfer

M&AE 423 Intermediate Fluid Dynamics

M&AE 427 Fluids/Heat Transfer Laboratory

M&AE 449 Combustion Engines

M&AE 490 Special Investigations in Mechanical and Aerospace Engineering

M&AE 491 Design Projects in Mechanical and Aerospace Engineering

M&AE 506 Aerospace Propulsion Systems

M&AE 507 Dynamics of Flight Vehicles

M&AE 543 Combustion Processes

Typical focus in Mechanical Systems/Design:

The following two courses:

ENGRD 202 Mechanics of Solids

ENGRD 203 Dynamics

One or more of the following:

M&AE 212 Mechanical Properties and Processing of Engineering Materials

M&AE 225 Mechanical Design and Synthesis

M&AE 325 Mechanical Design and Analysis

M&AE 326 System Dynamics

The remainder from this list, of which at least one course must satisfy requirement 1b:

M&AE 306 Spacecraft Engineering

M&AE 386/486 Automotive Engineering

M&AE 412 Smash and Crash: Mechanics of Large Deformations

M&AE 417 Introduction to Robotics: Dynamics, Control, Design

M&AE 463 Neuromuscular Biomechanics

M&AE 464 Orthopaedic Tissue Mechanics

M&AE 478 Feedback Control Systems

M&AE 479 Modeling and Simulation of Mechanical and Aerospace Systems

M&AE 490 Special Investigations in Mechanical and Aerospace Engineering

M&AE 491 Design Projects in Mechanical and Aerospace Engineering

M&AE 514 Design for Manufacture and Assembly

M&AE 565 Biomechanical Systems—Analysis and Design

M&AE 571 Applied Dynamics

Preparation in Aerospace Engineering

Although there is no separate undergraduate program in aerospace engineering, students may prepare for a career in this area by majoring in mechanical engineering and taking courses from the aerospace engineering concentration such as M&AE 305, 306, 506, and 507. Students may prepare for the graduate program in aerospace engineering by majoring in mechanical engineering, in other appropriate engineering specialties such as electrical engineering or engineering physics, or in the physical sciences. Other subjects recommended as preparation for graduate study include thermodynamics, fluid mechanics, applied mathematics, chemistry, and physics.

Master of Engineering (Aerospace) Degree Program

The M.Eng. (Aerospace) 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, non-equilibrium flows, combustion, dynamics and control, computational fluid dynamics, etc.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty advisor. Any subsequent changes must also be approved by the committee. An individual student's curriculum includes a four- to eight-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).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have an aerospace 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 the special approval of the M&AE Master of Engineering Committee.

The technical electives may be courses of appropriate level in mathematics, physics, chemistry, or engineering; a maximum of six credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. It is expected that all students will use technical electives to develop proficiency in mathematics beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

Students should check with the M&AE graduate field office (107 Upson Hall) for additional degree requirements.

Master of Engineering (Mechanical) Degree Program

The M.Eng. (Mechanical) 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 biomechanical engineering, combustion, propulsion and power systems, fluid mechanics, heat transfer, materials and manufacturing engineering, mechanical systems and design, etc.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. Any subsequent changes must also be approved by the committee. An individual student's curriculum includes a four- to eight-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 that constitute the major concentration 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 special approval of the M&AE Master of Engineering Committee.

The technical electives may be courses of appropriate level in mathematics, physics, chemistry, or engineering; a maximum of six credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. It is expected that all students will use technical electives to develop proficiency in mathematics beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

Students should check with the M&AE graduate field office (107 Upson Hall) for additional degree requirements.

Students enrolled in the M.Eng. (Mechanical) degree program may take courses that also satisfy the requirements of the manufacturing, energy, or electronic packaging option programs leading to special dean's certificates in those areas.

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.

Undergraduate Study

Although there is no special undergraduate field program 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 regular field programs (such as those in engineering physics, materials science and engineering, computer science, and civil, chemical, electrical, or mechanical engineering) or within the College Program.

Master of Engineering (Nuclear) Degree Program

The two-term curriculum leading to the M.Eng. (Nuclear) degree is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The course of study covers the basic principles of nuclear reactor systems with a major emphasis on reactor safety and radiation protection and control. The special facilities of the Ward Center for Nuclear Sciences are described in the *Announcement of the Graduate School.*

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate specializations. The recommended background is (1) an accredited baccalaureate degree in engineering, physics, or applied science; (2) physics, including atomic and nuclear physics; (3) mathematics, including advanced calculus; and (4) thermodynamics. Students should see that they fulfill these requirements before beginning the program. In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer. General admission and degree requirements are described in the college's introductory section.

The following courses, or equivalents, are included in the 30-credit program:

Fall term

NS&E 509, Nuclear Physics for Applications

NS&E 612, Nuclear Reactor Theory

NS&E 633, Nuclear Reactor Engineering

Technical elective

Spring term

NS&E 545, Energy Seminar

Technical elective

Engineering design project

Mathematics or physics elective

Engineering electives should be in a subject area relevant to nuclear engineering, such as energy conversion, radiation protection and control, feedback control systems, magnetohydrodynamics, controlled thermonuclear fusion, and environmental engineering. The list below gives typical electives.

A&EP 606/ECE 581, Introduction to Plasma Physics (fall, 4 credits)

A&EP 607, Basic Plasma Physics (spring, 4 credits)

A&EP 661, Microcharacterization (fall, 3 credits)

ECE 457, Silicon Device Fundamentals (fall, 4 credits with lab)

M&AE 478/CHEME 372, Feedback Control Systems (fall, 4 credits)

MS&E 459, Physics of Modern Materials Analysis (spring, 3 credits)

MS&E 603, Analytical Techniques for Materials Science (spring, 4 credits)

NS&E 484/A&EP 484/ECE 484/M&AE 459, Introduction to Controlled Fusion: Principles and Technology (spring, 3 credits)

NS&E 521, Radiation Effects in Materials (fall, 1–3 credits)

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

K. B. Athreya, A. Berndt, L. J. Billera, R. G. Bland, M. J. Eisner, E. Friedman, X. Guo, S. Henderson, P. L. Jackson, R. A. Jarrow, W. L. Maxwell, J. A. Muckstadt, N. Prabhu, P. Protter, J. Renegar, S. I. Resnick, R. Roundy, D. Ruppert, G. Samorodnitsky, D. Shmoys, E. Tardos, M. J. Todd, H. Topaloglu, L. E. Trotter, Jr., B. W. Turnbull

Bachelor of Science Curriculum in Operations Research and Industrial Engineering

The program is designed to provide a broad education in the techniques and modeling concepts needed to analyze and design complex systems and to provide an introduction to the technical and professional areas with which operations researchers and industrial engineers are concerned. The program prepares students for a wide range of careers including operations research, industrial engineering, entrepreneurship, information technology, operations management, consulting, financial engineering, financial services, and management.

The foundation of the B.S. curriculum is the development of basic skills in calculus, statistics, probability, mathematical programming, 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 OR&IE electives to broaden and deepen their expertise in applied probability and statistics, industrial systems, optimization, information technology, or financial engineering.

Because of the wide range of career goals among our students, the B.S. program is designed with a minimum of required courses and a large number of required electives. Students should consult with their field advisers to select electives that best meet their future goals.

The faculty have not sought ABET accreditation of the B.S. curriculum as a program in industrial engineering. Industrial engineering curricula, while excellent for preparing industrial engineers, do not have the flexibility that the wide range of our students requires. Nonetheless, by proper selection of field electives, graduates of the B.S. program can and do become highly successful and competent industrial engineers. (Exceptional students interested in pursuing graduate studies are encouraged to speak with their faculty advisers concerning an accelerated program of study.)

A student who intends to enter the field program in Operations Research and Engineering should plan to take Basic Engineering Probability and Statistics (ENGRD 270) after completing MATH 192. Early consultation with a faculty member of the school or with the associate director for undergraduate studies can be helpful in making appropriate choices. The required courses for the OR&IE field program and the typical terms in which they are taken are as follows:

Term 2, 3, or 4	*Credits*
ENGRD 211, Computers & Programming	3
ENGRD 270, Basic Engineering Probability and Statistics	3
Term 5	
OR&IE 320, Optimization I	4
OR&IE 350, Financial and Managerial Accounting	4
OR&IE 360, Engineering Probability and Statistics II	4
Humanities/Social Sciences elective	3
Field-approved elective	3
Term 6	
OR&IE 310, Industrial Systems Analysis (may be taken in term 4)	4
OR&IE 321, Optimization II	4
OR&IE 361, Introductory Engineering Stochastic Processes I	4
Behavioral science (organizational behavior)†	3
Humanities/Social Sciences elective	3

†The behavioral science requirement can be satisfied by any one of several courses, including the Johnson Graduate School of Management (JGSM) course, NCC 554 (offered only in the fall), which is recommended for those contemplating the pursuit of a graduate business degree, ILROB 170, 171, and 320, H ADM 115, H ADM 414, and others.

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

	Minimum credits
OR&IE 580, Simulation Modeling and Analysis	4
Either OR&IE 416 or OR&IE 480 (program design requirement)	4
Three upperclass OR&IE electives as described below	9
Two field-approved electives (at least 3 credits must be outside OR&IE)	6
Two Humanities/Social Sciences electives	6
Two approved electives	6

Available OR&IE electives are as follows:

Manufacturing and distribution systems: OR&IE 416, 451, 480, 481, 483, 518, 524, 525, and 562 and JGSM NBA 641

Optimization methods: OR&IE 431, 432, 434, 435, and 436

Applied probability and statistics: OR&IE 462, 464, 474, 476 (2 credits), 561, 563, 575 (2 credits), 576 (2 credits) and 577

Financial engineering: OR&IE 467, 468, 469, and 473.

Scholastic requirements for the field are: a passing grade in every course; a grade of C- or better in each of ENGRD 211 and 270, OR&IE 310, 320, 321, 350, 360, 361 and 580; an overall average of at least 2.0 for each term the student is enrolled in the school; an average of 2.0 or better for OR&IE field courses; satisfactory progress toward the completion of the degree requirements. The student's performance is reviewed at the conclusion of each term.

If a grade of C- or better is not earned in a required course in a student's first attempt, the course must be repeated within one year and a satisfactory grade attained before the next course in the sequence may be taken (OR&IE 321 and 361, in particular). Failure to achieve at least a C- in the second attempt will generally result in withdrawal from the program.

Operations Research and Engineering Honors Program

Eligibility

The bachelor of science degree with honors will be granted to students who, in addition to having completed the degree requirements, have satisfactorily completed the honors program in Operations Research and Industrial Engineering and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA of at least 3.5.

Content

An OR&IE honors program shall consist of at least nine credits beyond the minimum required for graduation in OR&IE, so that no part of the honors program can also be used to satisfy graduation requirements. The nine credits shall be from one or more of the following with at least four hours in the first category:

1. Advanced courses in OR&IE at the 500 level or above.
2. A significant research experience or honors project under the direct supervision of an OR&IE faculty member using OR&IE 499: OR&IE 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 OR&IE using OR&IE 490: Teaching in OR&IE, or ENGRG 470: Undergraduate Engineering Teaching.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member during the first semester of their junior year. A student must be in the honors program for at least two semesters before graduation.

Procedures

Each application to the OR&IE honors program must have a faculty adviser to supervise the honors program. The honors adviser need not be the student's faculty adviser. The application to the program shall be a letter from the student describing the specific proposed honors program and including the explicit approval of the honors adviser. Each program must be approved by the associate director, and any changes to the student's program must also be approved by the associate director of undergraduate studies.

Engineering Minor Programs

The School of Operations Research and Industrial Engineering currently offers three engineering minor programs: engineering statistics, industrial systems and information technology, and operations research and management science. (A student may not receive credit for more than one minor offered by the School of Operations Research and Industrial Engineering.) Descriptions and requirements for each program follow:

Minor in Engineering Statistics

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the engineering statistics minor: BEE, A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, MS&E.

This minor requires the student to develop expertise in engineering statistics. The goal of the program 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.

The requirements for the engineering statistics minor are outlined below. For further details consult the Operations Research and Industrial Engineering Undergraduate Programs Office, 202 Rhodes Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. Required Courses:

ENGRD 270 Basic Engineering Probability & Statistics

OR&IE 360 or ECE 310 Basic Engineering Probability & Statistics II or Introduction to Probability & Random Signals

II. Four courses (11 credits minimum) taken from the following list*:

OR&IE 361 or ECE 411 Introductory Engineering Stochastic Processes I or Random Signals in Communications/Signal Processing

OR&IE 476 Applied Linear Statistical Models

OR&IE 576 Regression

OR&IE 563 Applied Time Series Analysis

OR&IE 565 Applied Financial Engineering

OR&IE 575 Experimental Design

OR&IE 577 Quality Control

OR&IE 580 Simulation Modeling and Analysis

MATH 472 or BTRY 409 Basic Probability or Theory of Statistics

BTRY 602 Statistical Methods II

BTRY 603 or ILRST 411 Statistical Methods III or Statistical Analysis of Qualitative Data

ILRST 310 Statistical Sampling

ILRST 314 Graphical Methods for Data Analysis

ILRST 410 Techniques of Multivariate Analysis

*Other course options approved by petition in advance. The student should be aware that some of these courses require others as prerequisites. All these courses are cross-listed under the Department of Statistical Science.

Academic Standards: a letter grade of C- or better for each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Minor in Industrial Systems and Information Technology

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the industrial systems and information technology minor: BEE, A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, MS&E.

The aim of this minor is to provide an in-depth education in the issues involved in the design and analysis of industrial systems, and the tools from information technology that have become an integral part of the manufacturing process. Students will become familiar with the problems, perspectives, and methods of modern industrial engineering and be prepared to work with industrial engineers in designing and managing manufacturing and service operations. 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 the application area most closely associated with these techniques.

The requirements for the industrial systems and information technology minor are outlined below. For further details consult the Operations Research and Industrial Engineering Undergraduate Programs Office, 202 Rhodes Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. At least three of the following:

ENGRD 270 Basic Engineering Probability and Statistics

OR&IE 310 Industrial Systems Analysis

OR&IE 320 Optimization I

OR&IE 480 Information Technology for Operations Research and Industrial Technology

II. The remaining courses/credit hours from the following:

OR&IE 350 Financial and Managerial Accounting

OR&IE 416 Design of Manufacturing Systems

OR&IE 451 Economic Analysis of Engineering Systems

OR&IE 525 Production Planning and Scheduling Theory and Practice

OR&IE 552 Revenue Management

OR&IE 577 Quality Control

OR&IE 580 Simulation Modeling and Analysis

Academic Standards: A letter grade of C- or better for each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Minor in Operations Research and Management Science

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the operations research and management science minor: BEE, A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, MS&E.

The field of operations research and management science (OR/MS) aims to provide rational bases for decision making by seeking to understand and model complex situations and to use this understanding 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 for OR/MS, including mathematical programming, stochastic and statistical models, and simulation. The intent of this minor is that the student should obtain a broad knowledge of these fundamentals, rather than to train the student in a particular application domain. This way students can adjust their advanced courses and pursue either methodological or application-oriented areas of greatest interest and relevance to the overall educational goals of their program.

The requirements for the operations research and management science minor are outlined below. For further details consult the Operations Research and Industrial Engineering Undergraduate Programs Office, 202 Rhodes Hall.

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits), chosen as follows:

I. Choose three courses from the following list:

ENGRD 270 Basic Engineering Probability and Statistics

OR&IE 320 Optimization I

OR&IE 321 Optimization II

OR&IE 360 Engineering Probability and Statistics II

OR&IE 361 Introduction Engineering Stochastic Processes I

OR&IE 580 Simulation Modeling and Analysis

II. These courses are to be supplemented with additional OR&IE courses at the 300 level or higher, so that entire program includes at least six courses and at least 18 credits. For example, taking the remaining three options on this list would suffice.

Academic Standards: a letter grade of C- or better for each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Master of Engineering (OR&IE) Degree Program

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

General admission and degree requirements are described in the introductory "Degree Programs" secti[illegible] The M.Eng. (OR&IE) program is in[illegible] for three groups of students: gra[illegible] the undergraduate field program in [illegible] wish to expand their practical kn[illegible]he field; Cornell undergraduate[illegible] math-based fields who want to [illegible]ir exposure to OR&IE; and q[illegible]-Cornellians with strong backgr[illegible]other programs in the United Sta[illegible]ad.

To ensure con[illegible] program in two semesters, the [illegible]nt should have completed cou[illegible]lity and statistics and in compute[illegible]ell as four semesters of ma[illegible]gh differential equations, linear [illegible]ultivariate calculus.

Program requireme[illegible]core of OR&IE courses plu[illegible]tives chosen from a broad array [illegible]e choice of a particular elective [illegible] plus a specific project course results in completion of one of several options within the program. These include the applied operations research option, the manufacturing option, the financial engineering option, the systems engineering option, the information technology concentration, and the Semester in Manufacturing. These options are offered jointly with various other Cornell departments and schools and they provide the opportunity to interact on projects and in class with specialists in other engineering fields and in business. Many students select the applied operations research option, offered only by OR&IE, which has project teams made up entirely of OR&IE M.Eng. students and which offers the broadest choice of elective courses and career alternatives, in business and elsewhere. Students interested in an option other than the applied operations research option should obtain further information from the following: manufacturing option, Center for Manufacturing Enterprise, 207 Hollister Hall, 607–255–7757; financial engineering option and information technology option, 201 Frank H. T. Rhodes Hall, 607–255–9128; Semester in Manufacturing option, 304 Sage Hall, 607–255–4691; systems engineering option, 207 Hollister Hall, 607–255–7757. For students lacking an undergraduate degree in Operations Research, the financial engineering option, which is highly specialized, may entail additional prerequisites or more than two semesters.

I. For matriculants with preparation comparable to that provided by the undergraduate Field Program in Operations Research and Engineering:

Fall term	*Credits*
OR&IE 516, Case Studies	1
OR&IE 893, Applied OR&IE Colloquium	1
M.Eng. Project	1
Technical electives	12

Spring term	
OR&IE 894, Applied OR&IE Colloquium	1
M.Eng. Project	minimum of 4
Technical electives	10

II. For matriculants from other fields who minimally fulfill the prerequisite requirements (students who have the equivalent of OR&IE 520, 523, and 560 will take other OR&IE electives in their place):

Fall term	*Credits*
OR&IE 560, Engineering Probability and Statistics II	4
OR&IE 520, Optimization I	4
OR&IE 522, Topics in Linear Optimization	1
OR&IE 516, Case Studies	1
OR&IE 580, Simulation Modeling and Analysis	4
OR&IE 893, Applied OR&IE Colloquium	1
M. Eng. Project	1

Spring term	
OR&IE 523, Introduction to Stochastic Processes I	4
OR&IE 894, Applied OR&IE Colloquium	1
M.Eng. Project	minimum of 4
Technical electives	5

For both of the above pro forma schedules, at least 12 credit hours of the specified electives must be chosen from the list of courses offered by the School of Operations Research and Industrial Engineering. For scheduling reasons, some options may require an additional summer, depending on the student's preparation.

A minimum of 30 credit hours are required to complete this program. Additional program requirements exist and are described in the *Master of Engineering Handbook*, which is available in Room 201 Frank H. T. Rhodes Hall and on the web at www.orie.cornell.edu.

The project requirement can be met in a variety of ways. Common elements in all project experiences include working as part of a group of three to five students on an engineering design problem, meeting with a faculty member on a regular basis, and oral and written presentation of the results obtained. Most projects address problems that actually exist in manufacturing firms, financial firms, and service organizations such as hospitals.

Cooperative Program with the Johnson Graduate School of Management

Undergraduates majoring in operations research and industrial engineering 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 Twelve-Month M.B.A. Program of the Johnson Graduate School of Management (JGSM).

An advantage for OR&IE majors is that, as part of their undergraduate and/or M. Eng. curriculum, they study several subjects that are required for the M.B.A. degree. (This is because modern management is concerned with the operation of production and service systems, and much of the analytical methodology required to deal with operating decisions is the same as that used by systems engineers in designing these systems.) This early start on meeting the business-degree requirements permits degrees in two years rather than the usual three years for such a combination.

The details of planning courses for this program should be discussed with the admissions office of the JGSM. Since 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.

Further details and application forms may be obtained at the office of the School of Operations Research and Industrial Engineering, 201 Frank H. T. Rhodes Hall (or meng@cornell.edu), and at the admissions office of the Johnson Graduate School of Management (mba@johnson.cornell.edu).

The Knight Scholars program, open to Cornell engineering graduates, provides financial support for the M.Eng./M.B.A. combination. Further details are available in 146 Olin Hall, (607) 255–7413.

STATISTICAL SCIENCE DEPARTMENT

The universitywide Department of Statistical Science coordinates undergraduate and graduate study in Statistics and Probability.
A list of suitable courses can be found in the Interdisciplinary Centers, Programs, and Studies section at the front of this catalog.

SYSTEMS ENGINEERING

M. Campbell, R. D'Andrea, R. A. Davidson, E. Garcia, A. R. George, P. L. Jackson, J. A. Muckstadt, A. F. Myers, L. K. Nozick, R. O. Roundy, F. B. Schneider, B. Selman, C. A. Shoemaker, J. R. Stedinger, R. J. Thomas, H. Topaloglu, M. A. Turnquist.

Master of Engineering (Systems) Degree Program

The M.Eng. (Systems) degree program is a 30-credit (usually nine-course) curriculum designed to prepare students for professional practice. Applicants must hold an ABET-accredited (or equivalent) undergraduate degree in engineering. Those without such preparation will require course work beyond the graduate program's 30-credit minimum to fulfill the engineering preparation requirement. The general degree requirements and admissions information are described above in the section "Master of Engineering Degree Programs." Each student's program of study is designed individually in consultation with an academic adviser and approved by the Director of Graduate Studies for Systems.

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

1) SYSEN 510 Applied Systems Engineering I, SYSEN 520 Applied Systems Engineering II, Project Management (CEE 590), and a two-semester design project (SYSEN 590).
2) Electives may be taken from three categories of courses: Modeling and Analysis, Applications, and Systems Management. At least one course must be taken from the Modeling and Analysis category, and no more than one may be taken from the Systems Management category. A list of pre-approved electives is on the Systems Engineering web site at www.systemseng.cornell.edu.

THEORETICAL AND APPLIED MECHANICS

T. J. Healey, chair; J. A. Burns, K. B. Cady, C. Castillo-Chavez, H. D. Conway (Emeritus), J. M. Guckenheimer, C. Y. Hui, J. T. Jenkins, S. Mukherjee, S. L. Phoenix, R. H. Rand, P. Rosakis, A. L. Ruina, W. H. Sachse, S. Strogatz, Z. J. Wang, A. Zehnder

Undergraduate Study

The Department of Theoretical and Applied Mechanics is responsible for courses in engineering mechanics and engineering mathematics, some of which are part of the Common Curriculum.

Independent Major in Engineering Science

A student may enroll in the Independent Major in Engineering Science, which is sponsored by the Department of Theoretical and Applied Mechanics. The Independent Major is described in the section on undergraduate study in the College of Engineering.

Minor in Applied Mathematics

Eligibility

Engineering undergraduates affiliated with the following fields are eligible to participate in the Applied Mathematics minor: BEE, A&EP, CEE, CHEME, COM S, EAS, ECE, M&AE, MS&E, OR&IE. Contact persons: Richard Rand, 207 Kimball Hall, 255–7145, rhr2@cornell.edu, and Tim Healey, 211 Kimball Hall, 255–3738, tjh10@cornell.edu.

Requirements

To complete the minor, the student must take at least six courses beyond MATH 294, to be chosen as follows:

a) No more than one course may be chosen from any one of the groups 1, 2, 3, or 4.
b) At least three courses must be chosen from groups 5 and 6.
c) No more than one 200-level course may be chosen.
d) No more than one course may be chosen that is offered by the student's major department.

1. Analysis
   - T&AM 310 Advanced Engineering Analysis I
   - MATH 311 Introduction to Analysis
   - MATH 420 Differential Equations and Dynamical Systems
   - A&EP 321 Mathematical Physics I
2. Computational Methods
   - COM S/ENGRD 322 Introduction to Scientific Computation
   - BEE 449 Computational Tools for Engineers
   - CEE/ENGRD 241 Engineering Computation
   - OR&IE 320 Optimization I
3. Probability and Statistics
   - OR&IE/ENGRD 270 Basic Engineering Probability and Statistics
   - OR&IE 360 Engineering Probability and Statistics II

ECE 310 Introduction to Probability and Random Signals

CEE 304 Uncertainty Analysis in Engineering

4. Applications

A&EP 333 Mechanics of Particles and Solid Bodies

CHEME 323 Fluid Mechanics

CEE 331 Fluid Mechanics

CEE 371 Structural Behavior

ECE 425 Digital Signal Processing

MS&E 303 Thermodynamics of Condensed Systems

M&AE 323 Introductory Fluid Mechanics

5. Advanced Courses

Only one of the following three may be chosen:

T&AM 311 Advanced Engineering Analysis II

MATH 422 Applied Complex Analysis

A&EP 322 Mathematical Physics II

Only one of the following two may be chosen:

EE 411 Random Signals

OR&IE 361 Introductory Engineering Stochastic Proecesses I

Only one of the following two may be chosen:

COM S 381 Introduction to Theory of Computing

COM S 481 Introduction to Theory of Computing

Only one of the following two may be chosen:

M&AE 571 Applied Dynamics

T&AM 570 Intermediate Dynamics

Also, you can choose from:

COM S 482 Introduction to the Analysis of Algorithms

OR&IE 321 Optimization II

OR&IE 431 Discrete Models

OR&IE 435 Introduction to Game Theory

OR&IE 462 Introductory Engineering Stochastic Processes II

EE 522 Nonlinear Systems

T&AM 578 Nonlinear Dynamics and Chaos

T&AM 610 Methods of Applied Math I

T&AM 611 Methods of Applied Math II

6. Math Courses—Any 300+ level course offered by the Mathematics Department in algebra, analysis, probability/statistics, geometry, or logic, with the following exceptions:

1) MATH 311 or MATH 420, if any course from group 1 is chosen

2) MATH 422, if T&AM 311 or A&EP 322 are chosen from group 5

Academic Standards: A letter grade of C or better for each course in the minor.

Minor in Biomedical Engineering

Students entering in fall 2002 or later must enroll in the Biomedical Engineering Minor in the Biomedical Engineering Program (BMEP).

Eligibility

Students graduating in 2004 and 2005 in the College of Engineering are eligible to participate in the Biomedical Engineering Minor, unless they are also pursuing the Bioengineering Option. (Students may participate in either the Bioengineering Option OR the Biomedical Engineering minor, but not both.)

Requirements

To complete the minor, the student must take at least six courses (minimum of 18 credits) from the five groups listed below, with at least one course from each group. At least four of the six courses must be from outside the student's major. In addition to the six courses for a minimum of 18 credits, all students must take ENGRG 501, Bioengineering Seminar (1 credit).

Required Course: ENGRG 501, Bioengineering Seminar (1 credit)

I. Biomaterials and Biomechanics

BEE 365 (3) Properties of Biological Materials

MS&E 265 (3) or TXA 439 (2) Biological Materials and Their Synthetic Replacements

MS&E 463 (3) Neuromuscular Biomechanics

M&AE 464 (3) Orthopaedic Tissue Mechanics

M&AE 565 (3) Biomechanical Systems—Analysis and Design

M&AE 663 (3) Advanced Topics in Neuromuscular Biomechanics

M&AE 664 (3) Mechanics of Bone

BMEP 605.3 (1) Biomaterials

BMEP 606.2 (1) Artificial Organs and Tissue Engineering

BMEP 606.3 (1) Biomechanics of Musculoskeletal Systems

II. Biomedical Systems

BEE 453 (3) Computer-Aided Engineering: Applications to Biomedical and Food Processes

CHEME 481 (3) Biomedical Engineering

BEE 454 (3) Physiological Engineering

BMEP 605.1 (1) Cellular Dynamics and Cancer

BMEP 605.2 (1) Physiological Systems

BMEP 301 (3) Molecular Principles of Biomedical Engineering

III. Instrumentation

BEE 450 (4) Bioinstrumentation

BEE 458 (4) Introduction to Biotechnology

ECE 432 (3) MicroElectro Mechanical Systems (MEMS)

ECE 511 (3) Bioelectric Signal Analysis and Processing

BMEP 606.1 (1) Biomedical Instrumentation and Diagnosis

BEE 659/BEE 459 (4) Biosensors and Bioanalytical Techniques

IV. Molecular and Cell Biology

BIOGD 281 (5) Genetics

BIOGD 282 (2–3) Human Genetics

BIOMI 290 (3) Microbiology

BIOAP 316 (4) Cellular Physiology

BIOBM 330–333 (2–4) Principles of Biochemistry

BIOBM 432 (3) Survey of Cell Biology

V. Physiology

BIOAP 212 (3) Human Physiology

BIOAP 311 (3) Introductory Animal Physiology

BIOAP 313 (4) Histology: The Biology of the Tissues

BIOGD 389 (3) Embryology

BIONB 222 (3–4) Neurobiology and Behavior II: Introduction to Neurobiology

AN SC 427 (3) Fundamentals of Endocrinology

M&AE 463 (3) Neuromuscular Biomechanics

Academic Standards: A letter grade of C- or better for each course in the minor and a cumulative GPA of 2.0 or better for all courses in the minor.

Note: ENGRG 605–606 and M&AE 664 are graduate courses with limited enrollment. First preference will be given to graduate students.

Master of Engineering (Engineering Mechanics) Degree Program

This program emphasizes fundamentals in engineering science and applied mathematics. In this way the student is prepared to handle a wide variety of multidisciplinary problems. The program is designed for engineering students and students from the physical and mathematical sciences.

The degree program requires satisfactory completion of 30 credits of course work, including 12 credits that involve analysis, computation, design, or laboratory experience. Of these 12 credits, at least 6 must be earned in Theoretical & Applied Mechanics (T&AM). Up to 10 credits will be awarded for an M. Eng. project. The balance of the required 30 credits can be obtained as electives from T&AM or from other departments in the engineering, physical or mathematical sciences. As a consequence, the student has great flexibility in choosing a course of study tailored to his or her interests.

Projects may be chosen from the current interests of the faculty, including: nonlinear dynamics and chaos (with applications to problems in physics, engineering and biology), solid mechanics (fracture mechanics, nonlinear elasticity, shape-memory alloys, composite materials, ultrasonics and acoustics), fluid mechanics (granular materials), space mechanics (evolution of the solar system, planetary rings).

The Department of Theoretical and Applied Mechanics has several laboratories equipped for the fabrication and mechanical testing of composite materials and structures. Extensive computing resources are available for numerical computations, design, or other numerical- or simulation-research activities related to composites. The Materials Science Center, the Center for Theory and Simulation in Science and Engineering, and the Computer-Aided Design Instructional Facility provide additional state-of-the-art laboratories and computer resources.

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 three-digit number.

Engineering Communications	ENGRC
Engineering Distribution	ENGRD
Engineering General Interest	ENGRG
Introduction to Engineering	ENGRI
Biological and Environmental Engineering	BEE
Applied and Engineering Physics	A&EP
Chemical and Biomolecular Engineering	CHEME
Civil and Environmental Engineering	CEE
Computer Science	COM S
Earth and Atmospheric Sciences (formerly Geological Sciences)	EAS
Electrical and Computer Engineering	ECE
Materials Science and Engineering	MS&E
Mechanical and Aerospace Engineering	M&AE
Nuclear Science and Engineering	NS&E
Operations Research and Industrial Engineering	OR&IE
Theoretical and Applied Mechanics	T&AM

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 334 Independent Study in Engineering Communications

Variable credits (1–3). Letter grade. By arrangement 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 335 Communications for Engineering Managers

Fall, spring. 3 credits. Limited to 20 students per section. Designed for juniors and seniors. Prerequisite: two freshman writing seminars and field 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. (Note that absences are limited to three, after which sharp penalties occur.) Fulfills the college's technical-writing requirement. May be used as a Free or Approved Elective in expressive arts.

ENGRC 350 Engineering Communications

Fall and spring. 3 credits. Letter grade. 20 students per section. Designed for juniors and seniors. Prerequisite: two freshman writing seminars and field affiliation.

The ability to communicate well is a factor in being hired as well as being promoted; the higher an engineer rises, the more writing and presentation he/she will do. ENGRC 350 prepares students for these important 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 both 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 that absences are limited to three, after which sharp penalties occur.) Fulfills the college's technical-writing requirement. May be used as a Free or Approved Elective in expressive arts.

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 201 Introduction to the Physics and Chemistry of the Earth (also EAS 201)

Fall. 3 credits. Prerequisites: PHYS 112 or 207. L. M. Cathles.

This course covers the formation of the solar system: accretion and evolution of the earth; the rock cycle: radioactive isotopes and the geological time scale, plate tectonics, rock and minerals, earth dynamics, mantle plumes; the hydrologic cycle: runoff, floods and sedimentation, groundwater flow, contaminant transport; and the weathering cycle: chemical cycles, CO_2 (weathering), rock cycle, controls on global temperature (CO_2 or ocean currents), oil and mineral resources.

ENGRD 202 Mechanics of Solids (also T&AM 202)

Fall, spring. 4 credits. Prerequisite: PHYS 112, coregistration in MATH 192 or permission of instructor.

Covers: principles of statics, force systems, and equilibrium; frameworks; mechanics of deformable solids, stress, strain, statically indeterminate problems; mechanical properties of engineering materials; axial force, shearing force, bending moment, plane stress; bending and torsion of bars.

ENGRD 203 Dynamics (also T&AM 203)

Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in MATH 293, or permission of instructor.

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.

ENGRD 210 Introduction to Circuits for Electrical and Computer Engineers (also ECE 210)

Fall, spring. 3 or 4 credits. Corequisites: MATH 293 and PHYS 213. ECE majors must take 4 credits, includes a design project. Non-ECE majors can take 3 credits. All students must take the lab. Fall, J. C. Belina, C. E. Seyler; spring, M. C. Kelley.

This is a first course in electrical circuits and electronics that 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 closely coupled with the lectures and there is a final design project.

ENGRD 211 Computers and Programming (also COM S 211)

Fall, spring, summer. 3 credits. Prerequisite: COM S 100 or an 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 219 Mass and Energy Balances (also CHEME 219)

Fall. 3 credits. Corequisite: physical chemistry or permission of instructor. W. L. Olbricht.

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.

ENGRD 221 Thermodynamics (also M&AE 221)

Fall, spring, may be offered summer. 3 credits. Prerequisites: MATH 192 and PHYS 112.

The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, vapor and gas power systems, refrigeration, and heat pump systems. Combustion and chemical equilibrium. Examples and problems are related to contemporary aspects of power generation and broader environmental issues.

ENGRD 230 Introduction to Digital Logic Design

Fall, spring. 4 credits. Prerequisite: COM S 100. Fall, W. E. Swartz; spring, W. E. Speight.

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 241 Engineering Computation (also CEE 241)

Fall, spring. 3 credits. Prerequisites: COM S 100 and MATH 293. Corequisite: MATH 294. (Completion of MATH 294 is suggested.) W. D. Philpot, C. A. Shoemaker.

Introduction to numerical methods, numerical mathematics, and probability and statistics. Development of programming and graphics proficiency with MATLAB and spreadsheets. Numerical analysis topics considered are: accuracy, precision, Taylor-series approximations, truncation and round-off errors, condition numbers, operation counts, convergence, and stability. Included are numerical methods for solving engineering problems that entail roots of functions, simultaneous linear equations, regression, curve fitting, interpolation, numerical differentiation and integration, and ordinary and partial differential equations. Introduction to finite difference and finite element methods. Applications are drawn from different areas of engineering.

ENGRD 251 Engineering for a Sustainable Society (also BEE 251)

Spring. 3 credits. Corequisite: MATH 293

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.

ENGRD 252 The Physics of Life (also A&EP 252)

Fall. Prerequisites: MATH 192, CHEM 207 or 211, and co-registration in or completion of PHYS 213. L. Pollack.

This course 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 260 Principles of Biological Engineering (also BEE 260)

Spring. 3 credits. Corequisite: MATH 293.

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 then practice it in homework sets. Topic areas 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.

ENGRD 261 Mechanical Properties of Materials: From Nanodevices to Superstructures (also MS&E 261)

Fall. 3 credits. S. P. Baker.

The mechanical properties of materials (strength, stiffness, toughness, ductility, and so on) and their physical origins are examined. The relationship of the elastic, plastic, and fracture behavior to microscopic structure in metals, ceramics, polymers, and composite materials is explored. Effects of time and temperature on materials properties are discussed. The emphasis of this course is on considerations for design and optimum performance of materials and engineered objects.

ENGRD 262 Electronic Materials for the Information Age (also MS&E 262)

Fall. 3 credits. Prerequisite: MATH 192; corequisite PHYS 213 or permission of instructor. G. Malliaras.

The course examines the electrical and optical properties of materials. Topics covered 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 264 Computer-Instrumentation Design (also A&EP 264)

Fall, spring. 3 credits. Prerequisite: COM S 100. 1 lec, 1 lab. Not open (without instructor's permission) to seniors. T. Cool

Covers the use of a small computer in an engineering or scientific research laboratory. 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. Both C++ programming and graphical programming with LabVIEW™ are used for computer interfacing to hardware. A second goal of the course is to develop effective written communication skills in the context of science and engineering. Students prepare progress reports, technical reports, and formal articles based on the experiments.

ENGRD 270 Basic Engineering Probability and Statistics

Fall, spring, summer. 3 credits. Prerequisites: MATH 191 and 192. D. Dalthorp.

This course gives students a working knowledge of basic probability and statistics and their application to engineering. Computer analysis of data and simulation are included. Topics include random variables, probability distributions, expectation, estimation, testing, experimental design, quality control, and regression.

ENGRD 321 Numerical Methods in Computational Molecular Biology (also BIOBM 321 and COM S 321)

Fall. 3 credits. Prerequisites: at least one course in calculus such as MATH 106, 111, or 191 and a course in linear algebra such as MATH 221 or 294 or BTRY 417. COM S 100 or equivalent and some familiarity with iteration, arrays, and procedures.

An introduction to numerical computing using MATLAB organized around five applications: the analysis of protein shapes, dynamics, protein folding, score functions, and field equations. Students become adept at plotting, linear equation solving, least squares fitting, and cubic spline interpolation. More advanced problem-solving techniques that involve eigenvalue analysis, the solution of ordinary and partial differential equations, linear programming, and nonlinear minimization are also treated. The goal of the course is to develop a practical computational expertise with MATLAB and to build mathematical intuition for the problems of molecular biology. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, or 421.

ENGRD 322 Introduction to Scientific Computation (also COM S 322)

Spring, summer. 3 credits. Prerequisites: COM S 100 and MATH 222 or 294.

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. The MATLAB computing environment is used. Vectorization, efficiency, reliability, and stability are stressed. Special lectures cover parallel computation. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, or 421.

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 150 Engineering Seminar

Fall. 1 credit. First-year students only. S-U grades only.

Engineering freshmen meet weekly with their faculty advisers to discuss a range of engineering topics. Discussions may include the engineering curriculum and student programs, what different types of 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 250 Technology in Society (also ECE 250, HIST 250, S&TS 250)

Fall. 3 credits. A humanities elective for engineering students. R. R. Kline.

This course 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 298 Inventing an Information Society (also ECE 298, S&TS 292, and HIST 292)

Spring. 3 credits. Approved for humanities distribution. Cannot be taken for credit after ENGRG 198/ECE 198. R. R. Kline.

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 placed on the changing relationship between science and technology, the economic aspects of innovation, gender and technology, and other social relations of this technology.

ENGRG 323 Engineering Economics and Management (also CEE 323)

Spring, usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. Student must register under CEE 323. D. P. Loucks.

Introduction to engineering and business economics and to project management. Intended to give students a working knowledge of money management and how to make economic comparisons of alternative engineering designs or projects. 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 project-management problems.

ENGRG 360 Ethical and Social Issues in Engineering (also S&TS 360)

Spring. 3 credits. Open to sophomores. R. R. Kline.

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; whistleblowing; 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 461 Entrepreneurship for Engineers (also M&AE 461, OR&IE 452)

Fall. 3 credits. Enrollment open to upper-class engineers; others with permission of instructor.

For description, see M&AE 461.

ENGRG 678 Teaching Seminar

Fall, spring. 1 credit. S-U grades only.

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. All components are 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 freshman-level courses intended to introduce students to various aspects of engineering. They have no prerequisites and are always cross-listed with a department.

ENGRI 101 Introduction to Biomedical Engineering Analysis (also BMEP 101)

Spring. 1 credit. Requires concurrent registration in BIO G 110. Lec and lab. D. Grubb and S. Archer.

This class is integrated with BIO G 110 to provide examples of engineering analysis of biological topics described in BIO G 110. Emphasis on molecular, cellular, and physiological systems.

ENGRI 110 The Laser and Its Applications in Science, Technology, and Medicine (also A&EP 110)

Fall. 3 credits. A. Greta.

The principles of laser action, types of laser systems, elements of laser design, and applications of lasers in science, technology, and medicine are discussed. In the laboratory students build and operate a nitrogen laser. Demonstration experiments with several types of lasers illustrate phenomena such as holography, laser processing of materials, optical tweezers, and fiber optics.

ENGRI 111 Nanotechnology (also MS&E 111)

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 112 Introduction to Chemical Engineering (also CHEME 112)

Fall. 3 credits. Limited to freshmen. 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 113 Solving Environmental Problems for Urban Regions (also CEE 113)

Fall. 3 credits. Not open (without instructor's permission) to upper-division engineering students. M. L. Weber-Shirk.

Learn how to design: reservoirs to provide water during droughts, aqueducts to transport water, water treatment plants to prevent waterborne diseases, and landfills to minimize contamination of the environment. Take field trips, build a miniature water treatment plant, and explore new technologies for making safe drinking water.

ENGRI 115 Engineering Applications of Operations Research

Fall, spring. 3 credits. Enrollment not open to OR&IE upper-class majors.

An 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 116 Modern Structural Systems and Materials (also CEE 116)

Fall. 3 credits. R. A. Davidson.

Introduction to civil infrastructure engineering in the 21st century—the latest challenges civil engineers face, and the innovative techniques they are using to address them. Using case studies of famous structures and structural failures, students learn to identify different structural forms, explain qualitatively how each carries loads, apply basic engineering principles and mathematics to describe their behavior quantitatively, explain how they fail in earthquakes and other extreme events, learn strategies for improving their performance, and recognize their historical, economic, social, and political context. Nontraditional structures, such as aircraft and underground structures, are discussed as well. Includes a project to design, analyze, build, and test an engineering structure.

ENGRI 117 Introduction to Mechanical Engineering (also M&AE 117)

Fall. 3 credits. 2 lectures and 1 lab per week.

An introduction to fundamentals of engineering, with emphasis on mechanical and aerospace engineering. The lectures will cover a little from each aspect of mechanical and aerospace engineerings applied to how to design and analyze products or devices and their performance. 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. There will be a final project in which students use the information learned to design and manufacture a product.

ENGRI 118 Design Integration: A Portable CD Player (also MS&E 118 and T&AM 118)

Spring. 3 credits. W. Sachse.

This course examines the roles of various engineering disciplines on the design of a portable compact disc (CD) player. Students are introduced to elements of mechanical, electrical, materials, environmental, manufacturing, and computer engineering as related to the CD player. Laboratory sessions and demonstrations are used to illustrate the principles of design.

ENGRI 119 Biomaterials for the Skeletal System (also MS&E 119)

Fall. 3 credits. D. T. 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 covered include strength, corrosion, toxicity, wear, and bio-compatibility. Case studies of design lead to consideration of regulatory approval requirements and legal liability issues.

[ENGRI 120 Introduction to Biomedical Engineering (also CHEME 120)

Fall. 3 credits. Not offered 2003–2004.

Introduction to the fundamental science and engineering that spawned the biotechnology revolution—technologies of cell cultures, DNA, and antibodies—and the relationship between biomedical science, bioengineering, and the growing biomedical product industry. Case studies of the development of biotechnical processes, from discovery to clinical use, include processes for vaccines, antibiotics, cancer chemotherapy, protein pharmaceuticals, and organ transplantation.]

ENGRI 121 Fission, Fusion, and Radiation (also A&EP 121 and NS&E 121)

Spring. 3 credits. S-U grades optional for students outside the College of Engineering. K. B. Cady.

Lecture-laboratory course on the physical nature and biological effects of nuclear radiation; benefits and hazards of nuclear energy; light-water reactors, breeder reactors, and fusion reactors; and uses of nuclear radiation in research. Laboratory demonstrations involve Cornell's research reactor; detection of nuclear radiation; activation analysis using gamma-ray spectroscopy; neutron radiography; and pulsed power generators for fusion research.

ENGRI 122 Earthquake! (also EAS 122)

Spring. 3 credits. L. D. Brown.

The science of natural hazards and strategic resources is explored. This course covers techniques for locating and characterizing earthquakes, and assessing 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 124 Designing Materials for the Computer (also MS&E 124)

Spring. 3 credits. 3 lectures.

Introduces the materials, processes, and properties of the semiconductors, polymers, ceramics, and metals used in the microelectronics industry to form integrated circuits, electronic devices, and displays. This course examines lithographic processing, metallization, diffusion, ion implantation, oxidation, and other processes used in fabricating electronic devices and their packages. The technology of displays is discussed, including liquid crystal displays and light-emitting devices.

ENGRI 126 Introduction to Telecommunications

Spring. 3 credits. S. B. Wicker, staff.

This course introduces the technologies that underlie wired and wireless telecommunication systems. The course begins with an introduction to telephony and the public switched telephone network. Modems and cellular telephony are then introduced, along with ISDN and BISDN. The course concludes with an introduction to ATM and TCP/IP. The course includes both lectures and laboratory demonstrations. Students have the opportunity to design communication systems and to determine their performance through simulations.

ENGRI 127 Introduction to Entrepreneurship and Enterprise Engineering (also M&AE 127)

Spring. 3 credits. Open to all Cornell students regardless of major. No prerequisites.

This course provides 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. This course is considered an "Introduction to Engineering" course by the College of Engineering, and satisfies the curricular requirements for such a course. The course is intended for freshmen and is taught from this perspective and at that level.

ENGRI 130 Introduction to Nanoscience and Nanoengineering (also A&EP 130)

Fall, spring. 3 credits.

Lecture/laboratory course designed to introduce freshmen to some of the ideas and concepts of nanoscience and nanotechnology. Topics covered 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 will 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 172 Computation, Information, and Intelligence (also COM S 172)

Fall. 3 credits. Prerequisites: some knowledge of calculus.

An introduction to computer science using methods and examples from the field of artificial intelligence. Topics include game playing, search techniques, learning theory, compute-intensive methods, data mining, information retrieval, the web, natural language processing, machine translation, and the Turing test. This is not a programming course; rather, "pencil and paper" problem sets are assigned. Not open to students who have completed the equivalent of COM S 100.

ENGRI 185 Art, Archaeology, and Analysis (also EAS 200, and MS&E 285)

Spring. 3 credits. R. Kay.

An interdepartmental course on the use of techniques of science and engineering in cultural research. Includes applications of physical and physiological principles to the study of archaeological artifacts and works of art. Also covers historical and technical aspects of artistic creation. Students learn analyses by modern methods to deduce geographical origins, and for exploration, dating, and authentication of cultural objects. Does not meet liberal studies distribution requirement for Engineering.

APPLIED AND ENGINEERING PHYSICS

A&EP 110 The Laser and Its Applications in Science, Technology, and Medicine (also ENGRI 110)

Fall. 3 credits. A. Gaeta.

This is a course in the Introduction to Engineering series. For description, see ENGRI 110.

A&EP 121 Fission, Fusion, and Radiation (also ENGRI 121 and NS&E 121)

Spring. 3 credits. S-U grades optional for students outside the College of Engineering. K. B. Cady.

This is a course in the Introduction to Engineering series. For description, see ENGRI 121.

A&EP 130 Introduction to Nanoscience and Nanoengineering (also ENGRI 130)

Fall, spring. 3 credits.

This is a course in the Introduction to Engineering series. For description, see ENGRI 130.

AEP 217 Electricity and Magnetism (also PHYS 217)

Fall, spring. 4 credits. Prerequisites: approval of student's adviser and permission of the instructor; co-registration in PHYS 216 or knowledge of special relativity at the level of PHYS 116; MATH 192 or equivalent and co-registration in MATH 293 or equivalent. Staff.

Intended for students who have done well in PHYS 112 or 116 (or the equivalent) and in mathematics who desire a more analytic treatment than that of PHYS 213. At the level of Electricity and Magnetism by Purcell. Recommended for prospective engineering physics majors. A placement quiz may be given early in the semester, permitting those student who find the material too abstract or analytical to transfer into PHYS 213 without difficulty.

A&EP 252 The Physics of Life (also ENGRD 252)

Fall. Prerequisites: MATH 192, CHEM 207 or 211, and co-registration in or completion of PHYS 213. L. Pollack.

For description, see ENGRD 252.

A&EP 264 Computer-Instrumentation Design (also ENGRD 264)

Fall, spring. 3 credits. Prerequisites: COM S 100. 1 lec, 1 lab. not open (without instructor's permission) to seniors.

For description, see ENGRD 264.

A&EP 321 Mathematical Physics I

Fall, summer. 4 credits. Prerequisite: MATH 294. Intended for upper-level undergraduates in the 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; Mathematical Physics, by Butkov.

A&EP 322 Mathematical Physics II
Spring. 4 credits. Prerequisite: A&EP 321. Second of the 2-course sequence in mathematical physics intended for upper-level undergraduates in the physical sciences. B. Kusse.
Topics: 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; *Mathematical Physics*, by Butkov.

A&EP 324 Maple Supplement to Mathematical Physics 321 and 322
Spring. 1 credit. R. V. E. Lovelace.
The course gives a broad introduction to Maple in applications to problems of mathematical physics similar to those covered in A&EP 321 and 322. We use Maple to solve differential equations—both linear and nonlinear. We make extensive use of plotting capabilities of Maple. Additionally, we cover matrices, complex functions, Laplace and Fournier transforms (and FFTs), and group theory. We also give an introduction to LaTex.

A&EP 330 Modern Experimental Optics (see also PHYS 330)
Fall. 4 credits. Enrollment limited. Prerequisites: PHYS 214 or equivalent. E. Bodenschatz.
A 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.

A&EP 333 Mechanics of Particles and Solid Bodies
Fall, summer. 4 credits. Prerequisites: PHYS 112 or 116 and coregistration in A&EP 321 or equivalent or permission of instructor.
This course 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. (On the level of *Classical Dynamics*, by Marion and Thorton.)

A&EP 355 Intermediate Electromagnetism
Fall, summer. 4 credits. Prerequisites: PHYS 214 or 217 and coregistration in A&EP 321 or equivalent, or permission of instructor.
Topics: vector calculus, electrostatics, analytic and numerical solutions to Laplace's equation in various geometries, electric and magnetic multipoles, electric and magnetic materials, energy in fields, quasistatics, and magnetic circuit design. Emphasis is on developing proficiency with analyical and numerical solution techniques in order to solve real-world design problems.

A&EP 356 Intermediate Electrodynamics
Spring. 4 credits. Prerequisite: A&EP 355 and coregistration in A&EP 322 or equivalent, or permission of instructor.
Topics: electromagnetic waves, waveguides, transmission lines, dispersive media, radiation, special relativity, interference phenomena. Emphasis is on physical concepts and developing ability to design/analyze microwave circuits and antenna arrays.

A&EP 361 Introductory Quantum Mechanics
Spring. 4 credits. Prerequisites: A&EP 333 or PHYS 318; coregistration in A&EP 322 or equivalent and in A&EP 356 or PHYS 326.
A first course in the systematic theory of quantum phenomena. Topics include wave mechanics, the Dirac formalism, angular momentum, the hydrogen atom, and perturbation theory.

A&EP 363 Electronic Circuits (also PHYS 360)
Fall, spring. 4 credits. Prerequisites: PHYS 208 or 213 or permission of the instructor. No previous experience with electronics assumed; however, the course moves quickly through some introductory topics such as basic DC circuits. Fall term usually less crowded. 1 lec, 2 labs. Fall: E. Kirkland; spring: J. Alexander.
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.

A&EP 423 Statistical Thermodynamics
Fall. 4 credits. Prerequisite: introductory 3-semester physics sequence plus 1 year of junior-level mathematics.
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 Thermal Physics, by Kittel and Kroemer, and Statistical Physics, by Rosser.

A&EP 434 Continuum Physics
Spring. 4 credits. Prerequisites: A&EP 333 and 356 or equivalent.
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 438 possible. At the level of Lai, Rubin and Krempl, Continuum Mechanics, and Tritton, Introduction to Fluid Mechanics.

A&EP 438 Computational Engineering Physics
Spring. 3 credits. Prerequisites: COM S 100, A&EP 321, 333, 355, 361, or equivalent, or permission of instructor; coregistration in 361 permitted.
Numerical computation (derivatives, integrals, differential equations, matrices, boundary-value problems, relaxation, Monte Carlo methods, etc.) is introduced and applied to engineering physics problems that cannot by solved analytically (three-body problem, electrostatic fields, quantum energy levels, etc.). Computer programming required (in C or optionally C++, FORTRAN, or Pascal). Some prior exposure to programming assumed but no previous experience with C assumed.

A&EP 440 Quantum and Nonlinear Optics
Spring. 4 credits. Prerequisites: A&EP 356, A&EP 361, or equivalent.
An introduction to the fundamentals of the interaction of laser light with matter. Topics include the propagation of laser beams in bulk media and guided-wave structures, the origins of optical nonlinearities, harmonic generation, self-focusing, optical bistability, propagation of ultrashort pulses, solitons, 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.

A&EP 450 Introductory Solid State Physics (also PHYS 454)
Fall. 4 credits. Prerequisites: some exposure to quantum mechanics at the level of PHYS 443, A&EP 361, or CHEM 793 is highly desirable but not absolutely required.
An introduction to 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. Optical properties, magnetism, and superconductivity are covered 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.

A&EP 470 Biophysical Methods (also BIONB 470)
Spring. 3 credits. Prerequisites: solid knowledge of basic physics and mathematics through the sophomore level; some knowledge of cellular biology helpful but not required. Letter grades only.

An overview of the diversity of modern biophysical experimental techniques used in the study of biophysical systems at the cellular and molecular level. Topics covered 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.

A&EP 484 Introduction to Controlled Fusion: Principles and Technology (also ECE 484, M&AE 459, and NS&E 484)

Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students. Offered on demand.

For description, see NS&E 484.

A&EP 490/491 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.

A&EP 550 Applied Solid State Physics

Spring. 3 credits. Prerequisites: A&EP 356, 361, 423, 450 (or equivalent).

Directed at students who have had an introductory course in solid state physics at the level of Kittel. This course 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.

A&EP 607 Advanced Plasma Physics (also ECE 582)

Spring. 4 credits. Prerequisites: ECE 581 and A&EP 606. Offered on demand.

For description, see ECE 582.

A&EP 633 Nuclear Reactor Engineering (also NS&E 633)

Fall. 4 credits. Prerequisite: introductory course in nuclear engineering. Offered on demand. K. B. Cady.

For description, see NS&E 633.

A&EP 661 Microcharacterization

Fall. 3 credits. Prerequisites: introductory 3-semester physics sequence or an introductory course in modern physics. At the senior/first-year graduate level.

The basic physical principles underlying the many modern microanalytical techniques available for characterizing materials from volumes less than a cubic micron. Discussion centers on the physics of the interaction process by which the characterization is performed, the methodology used in performing the characterization, the advantages and limitations of each technique, and the instrumentation involved in each characterization method.

A&EP 662 Micro/Nano-fabrication and Processing

Spring. 3 credits.

An 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.

A&EP 663 Nanobiotechnology (also BIO G 663 and MS&E 563)

Spring. 3 credits. Letter grade only. C. Batt.

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 is held twice weekly with 75-minute classes. All lectures are teleconferenced to our NBTC associate institutes.

[A&EP 711 Principles of Diffraction (also MS&E 671)

Fall. 3 credits. Letter grades only. Not offered 2003–2004. J. D. Brock.

This course is a 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.]

A&EP 751 M ENG Project

Fall, spring. 6–12 credits TBA. Required for candidates for the M.Eng. (Engineering Physics) degree.

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.

A&EP 753 Special Topics Seminar in Applied Physics

Fall. 1 credit. Prerequisite: undergraduate physics. Required for candidates for the M.Eng. (Engineering Physics) degree and recommended for seniors in engineering 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.

BIOLOGICAL AND ENVIRONMENTAL ENGINEERING

For complete course descriptions, see the Biological and Environmental Engineering listing in the College of Agriculture and Life Sciences section or visit the department web site, www.bee.cornell.edu.

BEE 151 Introduction to Computing

Fall. 4 credits. Prerequisite: MATH 191 or equivalent (coregistration permissible). Each lab and recitation section limited to 22 students.

BEE 152 Computer Applications for Engineers

Spring. 3 credits. Prequisites: BEE 151 or equivalent, MATH 191.

Course comprises three one-credit modules: (1) MATLAB; (2) spreadsheets; and (3) presentation graphics.

BEE 200 The BEE Experience

Spring. 1 credit.

BEE 222 Bioengineering Thermodynamics and Kinetics

Spring. 3 credits. Prerequisites: MATH 192, BIO 100, PHYS 213, and one course in chemistry.

BEE 251 Engineering for a Sustainable Society (also ENGRD 251)

Spring. 3 credits. Corequisite: MATH 293.

BEE 260 Principles of Biological Engineering (also ENGRD 260)

Spring. 3 credits. Corequisite: MATH 293.

BEE 299 Sustainable Development: A Web-Based Course

Spring. 3 credits. Prerequisite: sophomore standing and above. S-U grades optional.

BEE 301 Energy Systems

Spring. 3 credits. Prerequisite: college physics.

BEE 325 Science and Technology of Environmental Management

Fall. 3 credits.

BEE 350 Biological and Environmental Transport Processes

Fall. 3 credits. Prerequisites: MATH 294 and fluid mechanics (coregistration permissible).

BEE 360 Molecular and Cellular Bioengineering

Spring. 3 credits. Prerequisite: biochemistry or A&EP 252.

BEE 365 Properties of Biological Materials
Spring. 3 credits. Prerequisites: ENGRD 202 (coregistration permissible).

BEE 371 Hydrology and the Environment
Spring. 3 credits. Prerequisite: 1 course in calculus.

BEE 411 Biomass Processing: Modeling and Analysis
Spring. 3 credits. Prerequisites: BEE 250, BEE 350 (or any course in heat and mass transport), BIOBM 331, 332, or BIOMI 290.

BEE 427 Water Sampling and Measurement
Fall. 3 credits. Prerequisites: soils and/or fluids or hydrology courses and MATH 191.

BEE 435 Principles of Aquaculture
Spring. 3 credits. Prerequisite: minimum junior standing.

BEE 450 Bioinstrumentation
Spring. 4 credits. Prerequisites: linear differential equations, physics or electrical science, computer programming, and use of spreadsheets.

BEE 453 Computer-Aided Engineering: Applications to Biomedical Processes (also M&AE 453)
Spring. 3 credits. Prerequisite: heat and mass transfer (BEE 350 or equivalent).

BEE 454 Physiological Engineering
Fall. 3 credits. Corequisite: fluid mechanics.

BEE 456 Biomechanics of Plants (also BIO PL 456)
Fall. 3 credits. Prerequisites: upper division undergraduate or graduate status, completion of introductory sequence in biology, and 1 year of calculus, or permission of instructor. S-U grades optional.

BEE 459 Biosensors and Bioanalytical Techniques
Spring. 4 credits. Prerequisites: biochemistry or permission of instructor.

BEE 464 Bioseparation Processes
Fall. 3 credits. Prerequisites: biochemistry, physics, MATH 112 or 192, BEE 260, or permission of instructor.

BEE 471 Geohydrology (also CEE 431 and GEOL/EAS 445)
Fall. 3 credits. Prerequisites: MATH 294 and ENGRD 202.
For description, see CEE 431.

BEE 473 Watershed Engineering
Fall. 3 credits. Prerequisite: fluid mechanics or hydrology.

BEE 474 Drainage and Irrigation Design
Spring. 3 credits. Prerequisites: fluid mechanics or hydrology.

BEE 475 Environmental Systems Analysis
Fall. 3 credits. Prerequisites: computer programming and 1 year of calculus.

BEE 476 Solid Waste Engineering
Spring. 3 credits. Prerequisites: 1 semester of physics and chemistry.

BEE 478 Ecological Engineering
Spring. 3 credits. Prerequisite: junior-level environmental quality engineering course or equivalent.

BEE 481 LRFD-Based Engineering of Wood Structures (also CEE 481)
Spring. 3 credits. Prerequisite: ENGRD 202.

BEE 484 Metabolic Engineering
Spring. 3 credits. Prerequisites: biochemistry or permission of instructor.

BEE 489 Engineering Entrepreneurship, Management and Ethics
Spring. 3 credits. Prerequisites: ENGRD 270 or CEE 304 or equivalent, junior standing.

BEE 493 Technical Writing for Engineers
Fall, spring. 1 credit. Corequisite: BEE 450/473.

BEE 494 Special Topics in Biological and Environmental Engineering
Fall, spring. 1–4 credits. S-U grades optional.

BEE 495 BEE Honors Research
Fall, spring. 1–6 credits. Prerequisites: enrollment in the BEE Honors Research Program.

BEE 496 Capstone Design in Biological and Environmental Engineering
Fall, spring. 1–3 credits. Corequisite: BEE 473 or BEE 478, or BEE 481 and permission of instructor. Completed independent study form (available in 140 Roberts Hall) is required to register.

BEE 497 Individual Study in Biological and Environmental Engineering
Fall, spring. 1–4 credits. Prerequisite: written permission of instructor and adequate ability and training for the work proposed. Normally reserved for seniors in upper two-fifths of their class. S-U grades optional. Completed independent study form (available in 140 Roberts Hall) is required to register.

BEE 498 Undergraduate Teaching
Fall, spring. 1–4 credits. Prerequisite: written permission of instructor. Completed independent study form (available in 140 Roberts Hall) is required to register.

BEE 499 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. Completed independent study form (available in 140 Roberts Hall) is required to register.

BEE 551/552 Agricultural and Biological Engineering Design Project
Fall, 551; spring, 552. 3–6 credits. Prerequisite: admission to the M.Eng. (Agricultural and Biological) degree program.

BEE 625 Science and Technology of Environmental Management
Fall. 3 credits. Prerequisite: graduate standing.

BEE 647 Water Transport in Plants
Fall. 2 credits. Offered alternate years.

BEE 649 Solute Transport in Plants
Fall. 2 credits. Offered alternate years.

BEE 651 Bioremediation: Engineering Organisms to Clean Up the Environment
Spring. 3 credits. Prerequisites: BIOMI 290 or BIOMI 398 or BIOMI 331 or permission of instructor.

BEE 652 Instrumentation: Sensors and Transducers
Spring. 3 credits. Prerequisites: linear differential equations, introductory chemistry and introductory physics, or permission of instructor.

BEE 655 Thermodynamics and Its Applications
Spring. 3 credits. Prerequisite: MATH 293 or equivalent.

BEE 671 Analysis of the Flow of Water and Chemicals in Soils
Fall. 3 credits. Prerequisites: 4 calculus courses and fluid mechanics.

BEE 672 Drainage
Spring. 4 credits. Prerequisites: BEE 471 or BEE 473. S-U grades optional.

BEE 673 Sustainable Development Seminar (also NBA 573)
Spring. 1–3 credits. Prerequisite: upper division undergraduate and graduate students or permission of instructor.

BEE 678 Nonpoint Source Models
Spring. 3 credits. Prerequisites: computer programming and calculus.

BEE 685 Biological Engineering Analysis
Spring. 4 credits. Prerequisite: T&AM 310 or permission of instructor.

BEE 687 Sustainable Bio-based Industries
Fall. 1 credit. Prerequisite: graduate standing.

BEE 694 Graduate Special Topics in Agricultural and Biological Engineering
Fall, spring. 1–4 credits. S-U grades optional.

BEE 697 Graduate Individual Study in Agriculture and Biological Engineering
Fall, spring. 1–6 credits. Prerequisite: permission of instructor. S-U grades optional.

BEE 700 General Seminar
Fall. 1 credit. S-U grades only.

BEE 750 Orientation to Graduate Study
Fall. 1 credit. S-U grades only. Limited to newly joining graduate students.

BEE 754 Watershed Management
Spring. 2–3 credits. Prerequisite: graduate standing or permission of instructor.

BEE 760 Nucleic Acid Engineering
Fall. 3 credits. Prerequisite: BEE 360 or permission of instructor.

BEE 771 Soil and Water Engineering Seminar
Fall, spring. 1–3 credits. Prerequisite: graduate status or permission of instructor. S-U grades optional.

BEE 781 Structures and Related Topics Seminar
Spring. 1 credit. Prerequisite: graduate status or permission of instructor. S-U grades only.

BEE 785 Biological Engineering Seminar
Spring. 1 credit. Prerequisite: graduate status or permission of instructor. S-U grades only.

BEE 787 Industrial Ecology of Agriculturally Based Bioindustries
Spring. 3 credits. Prerequisites: 1 year calculus, matlab, BEE 687, graduate standing.

BEE 800 Master's-Level Thesis Research
Fall, spring. 1–15 credits. Prerequisite: permission of adviser. S-U grades only.

BEE 900 Doctoral-Level Thesis Research
Fall, spring. 1–15 credits. Prerequisite: permission of adviser. S-U grades only.

BIOMEDICAL ENGINEERING PROGRAM

BMEP 101 Introduction to Biomedical Engineering Analysis (also ENGRI 101)
Spring. 1 credit. Requires concurrent registration in BIO G 110. Lecture and laboratory. D. Grubb and S. Archer.
For description, see ENGRI 101.

BMEP 265 Biological Materials and Their Synthetic Replacements (also MS&E 265)
Spring. 3 credits.
For description, see MS&E 265.

BMEP 301 Molecular Principles of Biomedical Engineering (also CHEME 401)
Fall. 3 credits. Prior course work in BIO G 110, BIO BM 330, BIO MI 290 or equivalent. Lec and lab. K. H. Lee, S. Archer.
Introduction to genomics, proteomics, bioinformatics, and computational biology with an emphasis on the engineering challenges for these areas. 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.

BMEP 302 Cellular Principles of Biomedical Engineering (also CHEME 402)
Spring. 3 credits. Prerequisite: BMEP 301 or permission of instructor. Lecture and laboratory. D. A. Putnam, S. Archer.
Integration of mammalian cell biology with engineering modeling principles, put into the context of medical pathology and disease states. Three modules comprising: 1) cell culture techniques/receptor ligand interactions, 2) cellular trafficking, and 3) signal transduction.

BMEP 330 Introduction to Computational Neuroscience (also BIONB 330, PSYCH 330, and COGST 330)
Fall. 3 credits. Limited to 25 students.
For description, see BIONB 330.

BMEP 360 Molecular and Cellular Bioengineering (also BEE 360)
Spring. 3 credits. Prerequisite: biochemistry or A&EP 252.
For description, see BEE 360.

BMEP 401 Biomedical Engineering Analysis of Metabolic and Structural Systems (also M&AE 466)
Fall. 3 credits. Prerequisite: prior course work in basic biology. Lec and lab. L. Bonassar, S. Archer.
Quantitative biology of the renal, respiratory, cardiovascular, and musculoskeletal systems. Biophysics and biomedical engineering of bone. Tissue engineering and biomechanics of soft tissue.

BMEP 402 Information Exchange in Biomedical Engineering Systems
Spring. 3 credits. Prerequisite: BMEP 401 or permission of instructor. Lec and lab. Staff.
Quantitative biology of the endocrine, nervous, and immune systems. Computation and mathematics of neural nets, communication among macroscale biocommunication systems.

BMEP 404 CDE in Biomedical System Design (also ECE 402)
Spring. 1–4 credits. Co- or prerequisites: at least one of ECE 425, ECE 476, ECE 453. J. C. Belina.
For description, see ECE 402.

BMEP 463 Neuromuscular Biomechanics (also M&AE 463)
Spring. 3 credits. Prerequisite: ENGRD 202 and 203, or permission of instructor. Offered alternate years.
For description, see M&AE 463.

BMEP 464 Orthopaedic Tissue Mechanics (also M&AE 464)
Spring. 3 credits. Prerequisites: ENGRD 202 and M&AE 325 or permission of instructor. Offered alternate years.
For description, see M&AE 464.

BMEP 481 Biomedical Engineering (also CHEME 481)
Spring. 3 credits. Prerequisite: CHEME 324 or equivalent or permission of instructor. W. L. Olbricht.
For description, see CHEME 481.

BMEP 501 Bioengineering Seminar (also BEE 501)
Fall, spring. 1 credit. For juniors, seniors, and graduate students only. Staff.
Broad survey of all aspects of bioengineering, including biomedical, bioprocess, biological, and bioenvironmental engineering and aspects of biotechnology. Sessions may be technical presentations or discussions. Sessions may occasionally be held outside of scheduled times.

BMEP 539 Biomedical Materials and Devices for Human Body Repair (also TXA 439)
Spring. 2–3 credits. Prerequisites: college Natural Science requirement (Chem. or Biol). C. C. Chu.
For description, see TXA 439. Extra project required; same lectures as TXA 439.

BMEP 565 Biomechanical Systems—Analysis and Design (also M&AE 565)
Fall. 3 or 4 credits. Prerequisites: undergraduate courses in dynamics and strength of materials (e.g., T&AM/ENGRD 202 and 203) and senior standing, graduate standing, or permission of instructor.
For description, see M&AE 565.

BMEP 570 Biophysical Methods (also BIONB 470 and A&EP 470)
Spring. 3 credits. Prerequisites: solid knowledge of basic physics and mathematics through the sophomore level; some knowledge of cellular biology helpful but not required. Letter grades only.
For description, see A&EP 470.

BMEP 578 Computer Analysis of Biomed Images (also ECE 578)
Spring. 4 credits. Prerequisite: permission of instructor. A. P. Reeves.
For description, see ECE 578

BMEP 605 Fundamentals of Biomedical Engineering I (also CHEME 605)
Fall. 1–4 credits (1 credit per section). Prerequisites: graduate standing in Engineering or Science; PHYS 213 and MATH 294 or equivalent. S-U grades optional for graduate students not majoring or minoring in biomedical engineering. Coordinator: M. L. Shuler.
A series of four-week modules on specialized topics.

605.1 Cellular Dynamics and Cancer
1 credit. Meets first third of term. Staff.
Basic concepts of cell biology. Mathematical models of cell cycle, receptor-mediated signaling, and cell adhesion. Conceptual approaches for engineering solutions to cancer.

605.2 Physiological Systems
1 credit. Meets second third of term. Staff.
Emphasis is on development of physiologically based pharmacokinetic models for drug delivery and on models of cardiovascular system, particularly blood flow.

605.3 Biomaterials
1 credit. Meets final third of term. C. C. Chu and staff.
The main objective of the biomaterials module is to provide students with an effective background in a wide range of biomaterials that include polymers, metals/alloys, and ceramics and that are currently used in human body repair. After completion of this module, students have the basic and some in-depth knowledge of what biomaterials are made of, how biomaterials contribute to the saving of human lives, the criteria of materials for biomedical use, biocompatibility, failure modes of biomaterials, the current R&D activities in biomaterials, challenges that biomaterials are facing, and future direction of R&D in biomaterials.

[605.4 Biomedical Engineering Project
1 credit. Meets final third of term. Must contact instructor before Friday of the third week of September. Not offered 2003–2004. M. L. Shuler.
Students work in teams on a design problem of their choice related to development of a biomedical device or procedure. Each team prepares a written report.]

BMEP 606 Fundamentals of Biomedical Engineering II (also CHEME 606)
Spring. 1–4 credits. Prerequisites: graduate standing in Engineering or Science; PHYS 213 and MATH 294 or equivalent. S-U grades optional for graduate students not majoring or minoring in biomedical engineering. Coordinator: M. L. Shuler.
A series of one and two-credit modules on specialized topics.

606.1 Biomedical Instrumentation and Diagnosis
1 credit. Lec. Meets second third of the term. Staff.
This course gives a perspective on the use of advanced instrumentation for the diagnosis and treatment of disease and the investigation of fundamental biological processes. The basic theory and application of different microscopic and spectroscopic methods, imaging tomographies, and micro-electromechanical devices to biological systems are explored.

606.2 Artificial Organs and Tissue Engineering

1 credit. Lec. Prerequisite: ENGRG 605, Section 03 (Biomaterials). Meets first third of term. L. Bonassar and staff.

An introduction to the use of cells, biological molecules, and synthetic materials as the basis for building artificial organs and encouraging tissue regeneration. The section discusses the physiological and engineering issues underlying the use of synthetic, extracorporeal systems (e.g., membrane-based dialysis devices), composite implantable materials and nerve regeneration guides), and hybrid cell/polymer implantable systems (e.g., engineered tissues).

606.3 Biomechanics of Musculoskeletal Systems

2 credits. Lec and lab. Meets final third of term. D. L. Bartel, C. E. Farnum.

Integrated lecture/laboratory experience. The anatomy and function of the canine hindlimb are explored in dissection laboratories and through demonstration of a non-invasive technique, computed tomography. Methods of approximating functional joint loads are discussed, and physical testing is demonstrated. A computer model of the stifle (knee) joint is created by combining knowledge of the anatomy and the mechanical environment.

BMEP 631 Engineering Principles for Drug Delivery (also CHEME 631)

Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.

Application of engineering principles (particularly diffusion, transport, and kinetics) to problems in drug formulation and delivery. Specific topics include traditional drug formulation, mechanisms and kinetics of pharmaceutical stability, transdermal systems, controlled release devices, prodrugs, targeted drug delivery, biomaterials, and governmental regulatory issues.

BMEP 663 Advanced Topics in Neuromuscular Biomechanics (also M&AE 663)

Spring. 3 credits. Permission of instructor only. Offered alternate years. F. Valero-Cuevas.

For description, see M&AE 663.

[BMEP 664 Mechanics of Bone (also M&AE 664)

Spring. 3 credits. Prerequisites: graduate standing or permission of instructor. Offered alternate years. Not offered 2003–2004.

For description, see M&AE 664.]

BMEP 665 Principles of Tissue Engineering (also M&AE 665 and MS&E 665)

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.

This course 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.

BMEP 760 Nucleic Acid Engineering (also BEE 760)

Fall. 3 credits. Prerequisite: BEE 360 or permission of instructor.

For description, see BEE 760.

CHEMICAL ENGINEERING

CHEME 112 Introduction to Chemical Engineering (also ENGRI 112)

Fall. 3 credits. Limited to freshmen. T. M. Duncan.

This is a course in the Introduction to Engineering series. For description, see ENGRI 112.

[CHEME 120 Introduction to Biomedical Engineering (also ENGRI 120)

Fall. 3 credits. Not offered 2003–2004.

This is a course in the Introduction to Engineering series. For description, see ENGRI 120.]

CHEME 219 Mass and Energy Balances (also ENGRD 219)

Fall. 3 credits. Corequisite: physical or organic chemistry or permission of instructor. W. L. Olbricht.

For description, see ENGRD 219.

CHEME 301 Nonresident Lectures

Spring. 1 credit. M. Ackley.

Lecturers from industry and from selected departments of the university provide information to assist students in their postgraduate plans.

CHEME 313 Chemical Engineering Thermodynamics

Fall. 4 credits. Prerequisite: physical chemistry II. F. A. Escobedo.

A study of the first and second laws and their consequences for chemical systems. 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 323 Fluid Mechanics

Spring. 3 credits. Prerequisites: CHEME 219 and engineering mathematics sequence. D. L. Koch.

Fundamentals of fluid mechanics. Macroscopic and microscopic balances. Applications to problems involving viscous flow.

CHEME 324 Heat and Mass Transfer

Fall. 3 credits. Prerequisite: CHEME 323. C. Cohen.

Fundamentals of heat and mass transfer. Macroscopic and microscopic balances. Applications to problems involving conduction, convection, and diffusion.

CHEME 332 Analysis of Separation Processes

Spring. 3 credits. Prerequisites: CHEME 313 and 323. Y. L. Joo.

Analysis of separation processes involving phase equilibria and mass transfer. Covers: phase equilibria; binary and multicomponent distillation; liquid-liquid extraction; gas absorption, absorption, membrane separations.

CHEME 372 Introduction to Process Dynamics and Control

Spring. 1 credit. Prerequisites: CHEME 313 and 323. A. B. Anton.

Modeling and analysis of the dynamics of chemical processes, Laplace transforms, block diagrams, feedback control systems, and stability analysis.

CHEME 390 Reaction Kinetics and Reactor Design

Spring. 3 credits. Prerequisites: CHEME 313 and 323. J. R. Engstrom.

A study of chemical reaction kinetics and principles of reactor design for chemical processes.

CHEME 391 Physical Chemistry II (also CHEM 391)

Spring. 4 credits. Limited to engineering students. T. M. Duncan.

For description, see CHEM 391.

CHEME 401 Molecular Principles of Biomedical Engineering (also BMEP 301)

Fall. 3 credits. Prerequisites: BIO G 110 or BIO BM 330. K. H. Lee.

For description, see BMEP 301.

CHEME 402 Cellular Principles of Biomedical Engineering (also BMEP 302)

Spring. 3 credits. D. Putnam.

For description, see BMEP 302.

CHEME 432 Chemical Engineering Laboratory

Fall. 4 credits. Prerequisites: CHEME 323, 324, 332, and 390. K. E. Ackley and staff.

Laboratory experiments in fluid dynamics, heat and mass transfer, kinetics, other operations. Correlation and interpretation of data. Technical report writing.

CHEME 462 Chemical Process Design

Spring. 4 credits. Prerequisite: CHEME 432. K. E. Ackley and staff.

A consideration of process and economic alternatives in selected chemical processes; design and assessment.

CHEME 470 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 472 Feedback Control Systems (also ECE 471 and M&AE 478)

Fall. 4 credits. Prerequisites: CHEME 372, ECE 301, M&AE 326, or permission of instructor. A. B. Anton and R. D'Andrea.

For description, see M&AE 478.

CHEME 480 Chemical Processing of Electronic Materials

Spring. 3 credits. A. B. Anton.

Introduction to chemical processing of semiconductor materials for the manufacture of microelectronic devices, with specific emphasis on thermodynamics, transport phenomena, and kinetics. Topics include semiconductor properties and behavior, microelectronic device operation, thermochemistry of deposition and etching reactions, vacuum transport, plasmas, PVD, oxidation, diffusion, CVD, and statistical process control.

CHEME 481 Biomedical Engineering (also BMEP 481)

Spring. 3 credits. Prerequisite: CHEME 324 or equivalent or permission of instructor. W. L. Olbricht.

Special topics in biomedical engineering, including cell separations, blood flow, design of artificial devices, biomaterials, image analysis, biological transport phenomena, pharmacokinetics and drug delivery, biomedical transducers (ECG and pace makers), and analysis of physiological processes such as adhesion, mobility, secretion, and growth.

CHEME 484 Microchemical and Microfluidic Systems

Fall. 3 credits. Prerequisite: CHEME 390 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 490 Undergraduate Projects in Chemical Engineering

Fall, spring. Variable credit.

Research or studies on special problems in chemical engineering.

CHEME 491 Undergraduate Teaching in Chemical Engineering

Fall. 1 credit. T. M. Duncan and M. Ackley.

Methods of instruction in chemical engineering acquired through discussions with faculty and by assisting with the instruction of freshmen and sophomores.

CHEME 520 Chemical, Polymer, Biomedical, and Electronic Materials Processing

Fall, spring. 1–6 credits (1 credit per section).

520.1 An Overview of Chemical Processing

Spring. 1 credit. Meets first third of term. Limited to nonchemical engineers. T. M. Duncan.

An introduction to chemical engineering design and analysis-mathematical modeling, graphical methods and dynamic scaling. Open to nonchemical engineers only.

520.2 Introduction to Biomedical Engineering

Spring. 1 credit. Meets first third of term. W. L. Olbricht.

Meets concurrently with CHEME 481.

520.3 Introduction to Electronic Materials Processing

Spring. 1 credit. Meets first third of term. A. B. Anton.

Meets concurrently with CHEME 480.

520.4 Introduction to Polymer Processing

Spring. 1 credit. Meets final second of term. L. A. Archer.

Overview and simple quantitative analyses of several plastic processes with an emphasis on the role of rheology in polymer processing.

520.5 Chemical Engineering Processing Units and Equipment

Spring. 1 credit. Meets first third of term. K. E. Ackley and A. M. Center.

The hardware of the chemical process and refining industries and their everyday evaluation and trouble shooting.

520.6 Introduction to Petroleum Refining

Fall. 1 credit. Meets second third of term. A. M. Center.

The petroleum refining industry including crude oil evaluation, fuel quality, refining processes, refinery configurations, and refinery economics.

520.7 Process Control Strategies

Spring. 1 credit. Meets first third of term. A. M. Center.

Meet concurrently with CHEME 470.

CHEME 543 Bioprocess Engineering

Spring. 3 credits. Prerequisite: CHEME 390 or permission of instructor. No prior background in the biological sciences required. M. L. Shuler.

A discussion of principles involved in using microorganisms, tissue cultures, and enzymes for processing. Application to food, fermentation, and pharmaceutical industries and to biological waste treatment.

CHEME 562 Managing Chemical Process Design

Spring. 1 or 2 credits. Prerequisite: CHEME 462. K. E. Ackley.

Guidance and evaluation of chemical process designs developed by teams of chemical engineers.

CHEME 565 Design Project

Fall, spring. 3 or 6 credits. Required for students in the M.Eng. (Chemical) program.

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 572 Managing New Business Development

Fall. 3 credits. Prerequisites: graduate standing; undergraduates must have permission of instructor. A. M. Center.

A case study approach introduces 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 590 Special Projects in Chemical Engineering

Fall, spring. Variable credit. Limited to graduate students.

Nonthesis research or studies on special problems in chemical engineering.

[CHEME 596 Systems on a Chip

Fall. 3 credits. Not offered 2003. P. Clancy.

Fundamentals of electronic chip fabrication processes for systems on a chip, the complexities of building devices on dissimilar substrates (e.g., Si on plastics), the creation of organic optoelectronic devices, and functional design integration issues. Applications to lab on a chip systems. Group design project required.]

CHEME 605 Fundamentals in Biomedical Engineering I (also BMEP 605)

Fall. 1–4 credits (1 credit per section). Prerequisites: graduate standing in Engineering or Science; PHYS 213 and MATH 294 or equivalent. Undergraduates must have permission of instructor and have completed BEE 454, CHEME 481, or M&AE 465. S-U grades optional for students not majoring or minoring in biomedical engineering.

For description, see BMEP 605.

CHEME 606 Fundamentals of Biomedical Engineering II (also BMEP 606)

Spring. 1–4 credits. Prerequisites: graduate standing in engineering or science; PHYS 213 and MATH 294 or equivalent. Undergraduates must have permission of instructor. S-U grades optional for students not majoring or minoring in biomedical engineering. Coordinator: M. L. Shuler.

A series of one- and two-credit modules on specialized topics. For description see BMEP 606.

CHEME 631 Engineering Principles for Drug Delivery (also BMEP 631)

Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.

For description, see BMEP 631.

CHEME 640 Polymeric Materials

Fall. 3 credits. C. Cohen.

Chemistry and physics of the formation and characterization of polymers. Principles of fabrication.

CHEME 644 Aerosols and Colloids

Fall. 3 credits. D. 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, rheological, and phase behaviors; and their role in technologies including paints, foods, health-care products, drug delivery, composite materials, and air pollution control.

CHEME 661 Air Pollution Control

Spring. 3 credits. P. H. Steen.

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 675 Synthetic Polymer Chemistry (also MS&E 622 and CHEM 671)

Fall. 4 credits. Prerequisites: CHEM 359–360 or equivalent or permission of instructor.

For description, see CHEM 671.

CHEME 711 Advanced Chemical Engineering Thermodynamics

Fall. 3 credits. Prerequisite: CHEME 313 or equivalent. P. Clancy.

Postulatory approach to thermodynamics. Legendre transformations. Equilibrium and stability of general thermodynamic systems. Applications of thermodynamic methods to advanced problems in chemical engineering. Introduction to statistical mechanical ensembles, phase transitions, Monte Carlo methods, and theory of liquids.

CHEME 713 Chemical Kinetics and Dynamics

Spring. 3 credits. Prerequisite: CHEME 390 or equivalent. F. Escobedo.

Topics include microscopic and macroscopic viewpoints; connections between phenomenological chemical kinetics and molecular reaction dynamics; reaction cross sections, potential energy surfaces, and dynamics of bimolecular 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 731 Advanced Fluid Mechanics and Heat Transfer
Fall. 3 credits. Prerequisites: CHEME 323 and 324 or equivalent. A. Stroock.
Topics include derivation of the equations of motion for Newtonian fluids; low Reynolds number fluid dynamics, lubrication theory, inviscid fluid dynamics; boundary layer theory; and convective and conductive heat transfer.

CHEME 732 Diffusion and Mass Transfer
Spring. 2 credits. Prerequisite: CHEME 731 or equivalent. L. A. Archer.
Conservation equations in multicomponent systems, irreversible thermodynamics, dispersion, and Brownian diffusion. Mass transfer for convective diffusion in liquids. Application to a variety of problems such as coagulation of aerosols, diffusion through films and membranes, liquid-liquid extraction, chemical vapor deposition, polymer rheology and diffusion, and reaction-diffusion systems.

CHEME 741 Selected Topics in Biochemical Engineering
Fall, spring. 1 credit (may be repeated for credit). Prerequisite: permission of instructor. K. H. Lee and M. L. Shuler.
Discussion of current topics and research in biochemical engineering for graduate students.

CHEME 745 Physical Polymer Science I
Fall. 3 credits. Corequisite: CHEME 711 or equivalent. Offered alternate years; offered 2003–2004. C. Cohen.
Covers thermodynamic properties of dilute, semidilute, and concentrated solutions from both classical and scaling approaches. Also covers characterization techniques of dilute solutions: osmometry, light scattering, viscometry, and sedimentation. Covers rubber elasticity; mechanical and thermodynamic properties of gels. Includes discussion of polymer melts: equations of state and glass transition phenomena.

CHEME 751 Mathematical Methods of Chemical Engineering Analysis
Fall. 4 credits. D. L. Koch.
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 753 Analysis of Nonlinear Systems: Stability, Bifurcation, and Continuation
Fall. 3 credits. Prerequisite: CHEME 751 or equivalent. Offered alternate years; offered 2003–2004. 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.

CHEME 790 Seminar
Fall, spring. 1 credit each term.
General chemical engineering seminar required of all graduate students in the field of chemical and biomolecular engineering.

CHEME 792 Principles and Practices of Graduate Research
Fall, spring. 1 credit. T. M. Duncan and staff.
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 890 Thesis Research
Fall, spring. Variable credit.
Thesis research for the M.S. degree in chemical engineering.

CHEME 990 Thesis Research
Fall, spring. Variable credit.
Thesis research for the Ph.D. degree in chemical engineering.

CIVIL AND ENVIRONMENTAL ENGINEERING

Courses in the School of Civil and Environmental Engineering are offered in three broad mission areas: Civil Infrastructure, Environment, and Systems Engineering and Information Technology. Within each mission area are 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 113 Solving Environmental Problems for Urban Regions (also ENGRI 113) (F,3cr.)

CEE 116 Modern Structural Systems and Materials (also ENGRI 116) (F,3cr.)

CEE 241 Engineering Computation (also ENGRD 241) (F,S,3cr.)

CEE 304 Uncertainty Analysis in Engineering (F,4cr.)

CEE 308 Introduction to CADD (F,S,1cr.)

CEE 309 Special Topics in Civil and Environmental Engineering (F,S,var.)

CEE 323 Engineering Economics and Management (also ENGRG 323) (S,Su,3cr.)

CEE 400 Senior Honors Thesis (F,S,var.)

CEE 401 Undergraduate Engineering Teaching in CEE (F,S,var.)

Civil Infrastructure

See also: CEE 116, CEE 241, CEE 304, CEE 308, CEE 503, and CEE 595

Geotechnical Engineering

CEE 341 Introduction to Geotechnical Engineering and Analysis (S,4cr.)

CEE 501/502 Design Project in Geotech/Structures (F,S,3cr.)

CEE 602 Civil Infrastructure Seminar (F,1cr.)

CEE 640 Foundation Engineering (F,3cr.)

CEE 641 Retaining Structures and Slopes (S,3cr.)

CEE 644 Environmental Applications of Geotechnical Engineering (S,3cr.)

CEE 649 Special Topics in Geotechnical Engineering (F,S,var.)

CEE 740 Engineering Behavior of Soils (F,3cr.)

CEE 741 Rock Engineering (S,3cr.)

CEE 744 Advanced Foundation Engineering (S,2cr.)

CEE 745 Soil Dynamics (S,3cr.)

CEE 746 Embankment Dam Engineering (S,2cr.)

CEE 749 Research in Geotechnical Engineering (F,S, var.)

CEE 840 Thesis—Geotechnical Engineering (F,S,var.)

Structural Engineering

CEE 116 Modern Structural Systems and Materials (F,3cr.)

CEE 371 Modeling of Structural Systems (S,4cr.)

CEE 376 Physical and Computational Material Simulation (S,4cr.)

CEE 472 Fundamentals of Structural Mechanics (F,3cr.)

CEE 473 Civil Infrastructure Design I (F,4cr.)

CEE 474 Civil Infrastructure Design II (S,4cr.)

CEE 475 Introduction to Composite Materials (S,4cr.)

CEE 479 Collaborative Distance Design of Structural Systems

CEE 501/502 Design Project in Geotech/Structures (F,S,3cr.)

CEE 602 Civil Infrastructure Seminar (F,S,1cr.)

CEE 671 Random Vibration (F,3cr.)

CEE 673 Engineering Analysis (F,3cr.)

CEE 674 Finite Element Modeling of Civil Infrastructure (S,3cr.)

CEE 675 Concrete Materials and Construction (S,3cr.)

CEE 676 Finite Element Analysis for Mechanical, Structural, and Aerospace Applications (S,3cr.)

CEE 677 Stochastic Problems in Science and Engineering (F,3cr.)

CEE 678 Structural Dynamics and Earthquake Engineering (S,3cr.)

CEE 770 Engineering Fracture Mechanics (F,3cr.)

CEE 774 Advanced Structural Concrete (F,3cr.)

CEE 775 Structural Concrete Systems (S,3cr.)

CEE 776 Advanced Design of Metal Structures (S,3cr.)

CEE 778 Fundamentals of Structural Mechanics (S,4cr.)

CEE 783 Civil and Environmental Engineering Materials Project (F,S,var.)

CEE 785 Research in Structural Engineering (F,S,var.)

CEE 786 Special Topics in Structural Engineering (F,S,var.)

CEE 880 Thesis—Structural Engineering (F,S,var.)

Environment

See also CEE 113, CEE 241, and CEE 304

Environmental Engineering

CEE 113 Solving Environmental Problems for Urban Regions (F,3cr.)

CEE 351 Environmental Quality Engineering (S,3cr.)

CEE 352 Water Supply Engineering (F,3cr.)

CEE 451 Microbiology for Environmental Engineering (F,3cr.)

CEE 453 Laboratory Research in Environmental Engineering (S,3cr.)

CEE 501/502 Design Project in Environmental Engineering (F,S,3cr.)

CEE 601 Water Resources and Environmental Engineering Seminar (F,1cr.)

CEE 653 Water Chemistry for Environmental Engineering (F,3cr.)

CEE 654 Aquatic Chemistry (S,3cr.)

CEE 655 Transport, Mixing, and Transformation in the Environment (F,3cr.)

CEE 659 Environmental Quality Engineering Seminar (S,1cr.)

CEE 750 Research in Environmental Engineering (F,S,var.)

CEE 755 Physical/Chemical Processes (F,3cr.)

CEE 756 Biological Processes (S,3cr.)

CEE 757 Physical/Chemical Processes Laboratory (F,2cr.)

CEE 758 Biological Processes Laboratory (S,2cr.)

CEE 759 Special Topics in Environmental Engineering (F,S,var.)

CEE 850 Thesis—Environmental Engineering (F,S,var.)

Environmental Systems

See Systems Engineering and Information Technology mission areas for a listing of courses in Environmental and Public Systems.

Environmental Fluid Mechanics and Hydrology

CEE 331 Fluid Mechanics (F,Su,4cr.)

CEE 332 Hydraulic Engineering (S,4cr.)

CEE 431 Geohydrology (also GEOL 445 and BEE 471) (F,3cr.)

CEE 432 Hydrology (S,3cr.)

CEE 436 Case Studies in Environmental Fluid Mechanics (S,4cr.)

CEE 437 Experimental Methods in Fluid Dynamics (S,3cr.)

CEE 501/502 Design Project in Fluid Mechanics and Hydrology (F,S,3cr.)

CEE 601 Water Resources and Environmental Engineering Seminar (F,1cr.)

CEE 631 Flow and Contaminant Transport Modeling in Groundwater (S,3cr.)

CEE 632 Hydrology (S,3cr.)

CEE 633 Flow in Porous Media and Groundwater (F,3cr.)

CEE 634 Boundary Layer Meteorology (F,3cr.)

CEE 635 Small and Finite Amplitude Water Waves (S,3cr.)

CEE 636 Environmental Fluid Mechanics (S,3cr.)

CEE 637 Experimental Methods in Fluid Dynamics (S,4cr.)

CEE 638 Hydraulics Seminar (S,1cr.)

CEE 639 Special Topics in Hydraulics (F,S,var.)

CEE 655 Transport, Mixing, and Transformation in the Environment (F,3cr.)

CEE 735 Research in Hydraulics (F,S,var.)

CEE 830 Thesis—Fluid Mechanics and Hydrology (F,S,var.)

Systems Engineering and Information Technology

See also CEE 113, CEE 241, and CEE 304

Engineering Management

CEE 490 Management Practice in Project Engineering (F,3cr.)

CEE 590 Project Management (F,S,4cr.)

CEE 591 Engineering Management Project (F,3cr.)

CEE 592 Engineering Management Project (S,3cr.)

CEE 593 Engineering Management Methods: Data, Information, and Modeling (F,3cr.)

CEE 594 Economic Methods for Engineering and Management (S,4cr.)

CEE 595 Construction Planning and Operations (F,3cr.)

CEE 597 Risk Analysis and Management (S,3cr.)

CEE 598 Introduction to Decision Analysis (S,4cr.)

CEE 692 Special Topics in Engineering Management (F,S,var.)

CEE 694 Research in Engineering Management (F,S,var.)

Environmental and Public Systems

CEE 323 Engineering Economics and Management (also ENGRG 323) (S,Su,3cr.)

CEE 501/502 Design Project in Environmental Systems (F,S,3cr.)

CEE 528 Public Political Economy (also ECON 569) (S,4cr.)

CEE 597 Risk Analysis and Management (S,3cr.)

CEE 620 Water Resources Systems Engineering (S,3cr.)

CEE 621 Stochastic Hydrology (S,3cr.)

CEE 623 Environmental Systems Engineering (F,3cr.)

CEE 628 Environmental and Water Resources Systems Analysis Seminar (S,1cr.)

CEE 722 Environmental and Water Resources Systems Analysis Research (F,S,var.)

CEE 729 Special Topics in Environmental and Water Resources Systems Analysis (F,S,var.)

CEE 820 Thesis—Environmental and Water Resources Systems (F,S,var.)

Remote Sensing

CEE 411 Remote Sensing: Environmental Applications (also CSS 411) (S,3cr.)

CEE 610 Remote Sensing Fundamentals (F,3cr.)

CEE 615 Digital Image Processing (S,3cr.)

CEE 617 Project—Remote Sensing (F,S,var.)

CEE 618 Special Topics—Remote Sensing (F,S,var.)

CEE 710 Research—Remote Sensing (F,S,var.)

CEE 810 Thesis—Remote Sensing (F,S,var.)

Systems Engineering

CEE 504 Applied Systems Engineering (also M&AE 591, ECE 512, OR&IE 512, SYSEN 510, COM S 504) (F,3cr.)

CEE 505 Applied Systems Engineering II (also M&AE 592, ECE 513, OR&IE 513, SYSEN 520, COM S 505) (S,4cr.)

CEE 506 Civil Infrastructure Systems (S,3cr.)

CEE 509 Heuristic Methods of Optimization (also COM S 574) (S,3cr.)

CEE 603 Systems Engineering and Information Technology Seminar (F,1cr.)

Transportation

CEE 361 Introduction to Transportation Engineering (S,Su,3cr.)

CEE 463 Transportation and Information Technology (F,3cr.)

CEE 464 Transportation Systems Design (S,3cr.)

CEE 561 Urban Transportation Planning and Modeling (F,3cr.)

CEE 762 Transportation Research (F,S,var.)

CEE 764 Special Topics in Transportation (F,S,var.)

CEE 860 Thesis—Transportation Engineering (F,S,var.)

CEE 113 Solving Environmental Problems for Urban Regions (also ENGRI 113)

Fall. 3 credits. Not open (without instructor's permission) to upper-division engineering students. Students must register under ENGRI 113. M. L. Weber-Shirk.

This is a course in the Introduction to Engineering series. For description, see ENGRI 113.

CEE 116 Modern Structural Systems and Materials (also ENGRI 116)

Fall. 3 credits. Students must register under ENGRI 116. R. A. Davidson.

This is a course in the Introduction to Engineering series. For description, see ENGRI 116.

CEE 241 Engineering Computation (also ENGRD 241)

Fall, spring. 3 credits. Prerequisites: COM S 100 and MATH 293. Corequisite: MATH 294 (completion of MATH 294 is suggested). Students must register under ENGRD 241. W. Philpot, C. A. Shoemaker.

For description, see ENGRD 241.

CEE 304 Uncertainty Analysis in Engineering

Fall. 4 credits. CEE Engineering Co-op students may substitute summer ENGRD 270. Prerequisite: first-year calculus. J. R. Stedinger.

Introduction to probability theory and statistical techniques, with examples from civil, environmental, and related disciplines. Course covers data presentation, commonly used probability distributions describing natural phenomona 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 308 Introduction to CADD

Fall, spring. 1 credit. Prerequisite: affiliation in CEE or permission of instructor. Course begins second full week of classes. J. F. Abel, J. J. Bisogni.

Learn to employ Computer Aided Design and Drafting (CADD) to construct 2D drawings and 3D models using a variety of AutoCAD 2000 techniques. Alternative software tools for solid modeling are introduced. Course meets in ACCEL once per week for eleven weeks, and grades are based on attendance, weekly exercises completed in class, and a semester project.

CEE 309 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 323 Engineering Economics and Management (also ENGRG 323)

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. D. P. Loucks.

For description, see ENGRG 323.

CEE 331 Fluid Mechanics

Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Prerequisite: ENGRD 202 (may be taken concurrently). 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.

[CEE 332 Hydraulic Engineering

Spring. 4 credits. Prerequisite: CEE 331. Offered alternate years. Not offered 2003–2004. M. L. Weber-Shirk.

Application of fluid-mechanical principles to problems of engineering practice and design: hydraulic machinery, water-distribution systems, open-channel design, river engineering, and pollutant dispersal. Lectures supplemented by laboratory work and a design project. See www.cee.cornell.edu/cee332/ for details.]

CEE 341 Introduction to Geotechnical Engineering and Analysis

Spring. 4 credits. Letter grade only. Prerequisites: ENGRD 202, CEE 331 (or equivalent), or permission of instructor. H. E. Stewart.

Fundamentals of geotechnical engineering. Topics covered 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 351 Environmental Quality Engineering

Spring. 3 credits. L. W. Lion.

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 352 Water Supply Engineering

Fall. 3 credits. Prerequisites: CEE 351 and previous/concurrent enrollment in CEE 451 or BIOMI 290. J. J. Bisogni.

Analysis of contemporary threats to human health from water supplies. Criteria and standards for potable-water quality. Water-quality control theory. Design of water supply facilities.

CEE 361 Introduction to Transportation Engineering

Spring; usually offered in summer for Engineering Co-op Program. 3 credits. J. Mbwana and A. H. Meyburg.

Introduction to technological, economic, and social aspects of transportation. Emphasis is on 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 371 Modeling of Structural Systems

Spring. 4 credits. Prerequisite: ENGRD 202. J. F. Abel.

Analytical and computational modeling of structural systems. The course is built on case studies involving different scales and different materials such as modern steel bridges, soil-foundation-structure systems, micro-electromechanical structures (MEMS), and aerospace vehicle structures. Topics include: analytical methods for solving statically determinate systems; virtual work principles for determination of kinematic and static unknowns; matrix formulation of the flexibility and stiffness methods of structural analysis for statically indeterminate systems; linear members (2D truss, frame); and an introduction to finite element modeling of continua.

CEE 376 Physical and Computational Material Simulation

Spring. 4 credits. Prerequisites: ENGRD 202, CEE 371. Staff.

Material failure phenomena such as fracture, plastic yielding and buckling in metals, plastics, polymeric and cement-based composites including concrete, and smart materials. Material response presented through experimental observation of physical behavior, theories for predicting response and methods for computational simulation. Practical considerations for material use in civil infrastructure. Weekly lab meetings including fabrication, experimentation and simulation of materials.

CEE 400 Senior Honors Thesis

Fall, spring. 1–6 credits. Staff.

Available to students admitted to the CEE Honors Program. Supervised research, study, and/or project work resulting in a written report or honors thesis.

CEE 401 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 402 Engineers without Frontiers

Fall, spring. 2 credits. R. A. Davidson and J. Mbwana. Students may enroll for credit for a maximum of 4 semesters.

Students undertake engineering-based group service projects in cooperation with partner community organizations. The projects, which may be local or international, offer real-life engineering research and design experience from problem formulation through implementation. Students work on interdisciplinary teams with a project supervisor (i.e., faculty or practicing engineer) and a representative from the partner community organization. Projects are selected based on academic content, potential significance to the partner community, commitment of the partner community organization, and student safety. The instructors coordinate with the Cornell chapter of Engineers without Frontiers.

CEE 411 Remote Sensing: Resource Inventory Methods (also CSS 411)

Spring. 3 credits. Prerequisite: permission of instructor. S. C. DeGloria.

For description, see CSS 411.

[CEE 431 Geohydrology (also GEOL/EAS 445 and BEE 471)

Fall. 3 credits. Prerequisites: MATH 294 and ENGRD 202. Not offered 2003–2004. L. Cathles.

Intermediate-level study of aquifer geology, groundwater flow, and related design factors. Includes description and properties of natural aquifers, groundwater hydraulics, soil water, and solute transport.]

CEE 432 Hydrology

Spring. 3 credits. Prerequisite: CEE 331. Intended for undergraduates. Lectures concurrent with CEE 632. 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 632.

CEE 436 Case Studies in Environmental Fluid Mechanics

Spring. 4 credits. Prerequisite: CEE 331 or equivalent. 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 laboratory/field projects. Course includes a design project.

[CEE 437 Experimental Methods in Fluid Dynamics

Spring. 3 credits. Not offered 2003–2004. E. A. Cowen.

Same as CEE 637 but no project is required. For description, see CEE 637.]

CEE 451 Microbiology for Environmental Engineering

Fall. 3 credits. Prerequisite: two semesters of college chemistry. R. E. Richardson.

An introduction to fundamental aspects of microbiology, organic chemistry, and biochemistry pertinent to environmental engineering. Topics include: principal characteristics and reactions of organic molecules; characteristics of Bacteria, (archaea, unicellular eukaryotes, fungi, algae, protozoa) and viruses relevant to water, wastewater and groundwater; pathogens, disease, and immunity; environmental influences on microorganisms; bioenergetics; enzymes and metabolism; microbial genetics; molecular microbiology and microbial ecology. This is an introductory course; consequently, it is inappropriate for those who have taken BIOMI 290 or equivalent.

CEE 453 Laboratory Research in Environmental Engineering

Spring. 3 credits. Prerequisites: CEE 351 or permission of instructor. M. L. Weber-Shirk.

Laboratory investigations of reactor flow characteristics; acid rain/lake chemistry; contaminated soil-site assessment, risk assessment, and remediation; pollutant dispersion/transport in rivers; drinking water filtration for pathogen removal; oxygen sag in rivers; and biodegradation in landfills. Design of laboratory experiments, development of laboratory methods, and use of experimental data are emphasized. See www.cee.cornell.edu/cee453/ for more information.

CEE 463 Transportation and Information Technology

Fall. 3 credits. M. A. Turnquist.

Improving the use of existing facilities has become an important objective in transportation planning. This course examines the role of computer and telecommunications technologies to achieve these improvements. Specific attention is focused on the development of analyses to evaluate the benefits of inclusion of these technologies in transportation systems.

CEE 464 Transportation Systems Design

Spring. 3 credits. Prerequisite: CEE 361. Staff.

Advanced techniques for physical and operational design of transportation systems, including analytical modeling techniques underlying design criteria. Evaluation of alternative designs. Management and operating policies, including investment strategies. Facility location decisions, networks, and passenger and freight terminals.

CEE 472 Fundamentals of Structural Mechanics

Fall, summer. 3 credits. Prerequisites: ENGRD 202, MATH 294. Primarily for seniors or by permission of the instructor. M. D. Grigoriu.

The course covers geometric definitions of deformation, rotation, and strain; small-strain theory; and the concept of stress. Students will learn about equilibrium and conservation of energy and the concept of virtual work. Other course topics include elasticity, basic plasticity, failure criteria for design, plane stress and plane strain, stress function solutions, torsion, beam and plate theory, and buckling. There will be two lectures and a recitation per week.

CEE 473 Civil Infrastructure Design I

Fall. 4 credits. Prerequisites: CEE 341 and 376 or permission of instructor. K. C. Hover.

Behavior and design of reinforced concrete and structures. Discussion of how forces are transferred through elements of building system. Includes a semester project requiring the design of a reinforced concrete structure.

CEE 474 Civil Infrastructure Design II

Spring. 4 credits. Prerequisite: CEE 341 and 376 or permission of instructor. K. C. Hoover.

Behavior and design of steel members, connections, and structures. Discussion of structural systems for buildings and bridges.

CEE 475 Introduction to Composite Materials (also M&AE 455, MS&E 555, and T&AM 455)

Spring. 4 credits. L. Phoenix.

For description, see T&AM 455.

CEE 479 Collaborative, Distance Design of Structural Systems (also M&AE 491)

Fall, spring. 8 credit hours. Students who enroll in CEE 479 are expected to take it in both the fall and spring semesters. A. Ingraffea, R. Davidson, L. Nozick, S. Jones.

This is a new senior-level design course, funded by NASA and the state of New York and taught jointly with Syracuse University. It emphasizes teamwork, collaboration at a distance, and multidisciplinary activities. The project is based on structural systems for a reusable launch vehicle. The course involves design, analysis, simulation, building, testing, virtual reality, and synchronous and asynchronous learning environments. First semester covers conceptual design, study of advanced mechanics, materials, software applications, risk and cost analysis. The second semester involves detailed design, construction, testing, and simulation.

CEE 481 LRFD-Based Engineering of Wood Structures (also BEE 481)

Spring. 3 credits. Prerequisite: ENGRD 202.

For description see BEE 481 in the College of Agriculture and Life Sciences section of this catalog.

CEE 490 Management Practice in Project Engineering

Fall. 3 credits. Prerequisite: permission of instructor. K. C. Hover.

An introduction to the principles of project management. Planning, organizing, communicating, scheduling, and controlling of engineering work done in project teams.

CEE 501/502 Design Project

Fall, spring. 3 credits each term. Required for students in the M.Eng. (Civil) 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 501/502 Design Project in Geotech Structures

Design of major civil engineering project. Planning and preliminary design during the fall term; final design completed in January intersession.

CEE 501/502 Design Project in Environmental Fluid Mechanics and Hydrology

Design of a major fluid mechanics/hydrology project.

CEE 501/502 Design Project in Environmental Engineering

Design of a major environmental engineering project.

CEE 501/502 Design Project in Environmental Systems

Design of a major environmental systems project.

CEE 503 Professional Practice in Engineering

Fall. 3 credits. Required for and limited to students in the M.Eng. (Civil) program. C. H. Trautmann.

Financial, legal, regulatory, ethical, and business aspects of engineering practice are examined in detail. Students are expected to develop their understanding of the interrelations among the physical, social, economic, and ethical constraints on engineering design.

CEE 504 Applied Systems Engineering I (also COM S 504, ECE 512, M&AE 591, OR&IE 512, SYSEN 510)

Fall. 3 credits. Prerequisite: senior or graduate standing in engineering, or permission of instructor. R. Roundy/ M. E. Campbell.

For description, see SYSEN 510.

CEE 505 Applied Systems Engineering II (also COM S 505, ECE 513, M&AE 592, OR&IE 513, SYSEN 520)

Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512 or SYSEN 520). L. Nozick, P. Jackson, and R. Thomas.

For description, see SYSEN 520.

CEE 506 Civil Infrastructure Systems

Spring. 3 credits. Letter or S-U. Prerequisites: Probability and statistics (CEE 304 or equivalent) and Engineering economics (CEE 323 or equivalent). L. K. Nozick.

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, will be examined through case studies related to civil infrastructure.

CEE 509 Heuristic Methods for Optimization (also COM S 572)

Spring. 3 or 4 credits. Prerequisites: CEE/ENGRD 241 or COM S/ENGRD 211 or 222 or graduate standing or permission of instructor. Not offered every year. C. A. Shoemaker and B. Selman.

This course describes a variety of heuristic search methods including simulated annealing, tabu search, genetic algorithms, derandomized evolution strategy, random walk, and direct search algorithms. Algorithms are used to find values of discrete and/or continuous variables arising in optimization and model fitting. Applications are discussed in a range of areas including some of the following: artificial intelligence, scheduling, protein folding, economic planning, water quality protection, telecommunications, and robotics. The advantages and disadvantages of heuristic search methods for both serial and parallel computation are discussed in comparison to other optimization algorithms.

[CEE 528 Public Political Economy (also ECON 639)

Spring. 4 credits. Not offered 2003–2004. R. E. Schuler.

For description, see ECON 639.]

[CEE 561 Urban Transportation Planning and Modeling

Fall. 3 credits. Prerequisites: CEE 361, statistics and probability, or permission of instructor. Designed for seniors with appropriate background and graduate students from CEE, CRP, and CIPA. Not offered 2003–2004. A. H. Meyburg.

This course exposes students to modern transportation planning practice and to the analytical tools necessary to engage in this field. Emphasis is on passenger transportation in the urban context. The course discusses the legislative, political, and economic contexts of urban transportation planning (UTP). It presents the travel demand estimation process and the associated models and approaches. Finally, it evaluates the forecasting results and assesses energy and environmental impacts. Student projects are an important element of the course.]

CEE 590 Project Management

Fall, spring. 4 credits. Prerequisite: permission of instructor. A. H. Meyburg and F. J. Wayno.

A core graduate course in project management for people who will manage technical or engineering projects. Focuses both on the "technical" tools of project management (methods for planning, scheduling, and control) and the "human" side (forming a project team, managing performance, resolving conflicts, etc.), with somewhat greater emphasis on the latter.

CEE 591 Engineering Management Project

Fall. 3 credits. Prerequisite: permission of instructor. P. Carr and J. Mbwana.

An 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 592 Engineering Management Project

Spring. 3 credits. Prerequisite: permission of instructor. P. Carr and J. Mbwana.

A continuation of CEE 591.

CEE 593 Engineering Management Methods: Data, Information, and Modeling

Fall. 3 credits. Prerequisites: CEE 323 and CEE 304 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 project design, scheduling, operation, quality control, forecasting, and resource allocation.

CEE 594 Economic Methods for Engineering and Management

Spring. 4 credits. Prerequisite: calculus, probability and statistics, and a course in economics. For seniors and graduate students or by permission of instructor. R. E. Schuler.

Economic concepts are introduced and used to select, calibrate and apply proper analytic decision tools in engineering design and management. Topics covered include: market analysis and pricing strategies; production choices and cost estimation; input acquisition and employee motivation; project evaluation and the cost of capital; decision-making in risky and uncertain environments; industry structure, bidding strategies and game theory; plus the regulatory and ethical consequences of overall managerial strategies.

CEE 595 Construction Planning and Operations

Fall. 3 credits. P. Carr.

A course on the fundamentals of construction planning: organization of the work site; construction planning, scheduling, and cost estimating; bidding; temporary structures; applications of computer methods; and the relationships among owners, designers, contractors, suppliers, and developers.

CEE 597 Risk Analysis and Management

Spring. 3 credits. Prerequisite: An introduction to probability and statistics course such as: CEE 304, ENGRD 270, ILSRT 210, BTRY 261 or AEM 210; and two semesters of calculus. For seniors and graduate students or by permission of instructor. J. R. Stedinger.

Course develops a working knowledge of risk terminology and reliability engineering, analytic tools and models used to analyze environmental and technological risks, and social and psychological risk issues. Discussions address life risks in the United States, natural hazards, transportation risks, industrial accidents, waste incineration, air pollution modeling, public health, regulatory policy, risk communication, and risk management.

CEE 598 Introduction to Decision Analysis

Spring. 3 credits. Prerequisite: an introduction to probability and statistics course such as CEE 304, ENGRD 270, ILSRT 210, BTRY 261 or AEM 210. For seniors and graduate students or by permission of instructor. R. A. Davidson.

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 601 Water Resources and Environmental Engineering Seminar

Fall. 1 credit. J. R. Stedinger.

Presentation of topics of current interest.

CEE 602 Civil Infrastructure Seminar

Fall, spring. 1 credit. Required for first-year graduate students. Staff.

Presentation of topics of current interest.

CEE 603 Systems Engineering and Information Technology Seminar

Fall, spring. 1 credit. Staff.

Presentation of topics of current interest.

CEE 605 Issues in Risk Analysis Seminar

Fall. 1 credit. S-U option. Staff.

Discussion of current issues and ongoing research on risk analysis issues from many perspectives with an emphasis on environmental risk analysis. Speakers address problem formulation, quantitative/qualitative methods in assessment of risk, communication issues, and challenges to risk assessment methodologies. Some sessions held jointly with other seminar series. Enrollment in seminar requires short reports and participation in two required discussion meetings for class members designed to integrate the issues raised during the semester.

CEE 610 Remote Sensing Fundamentals (also CCS 660)

Fall. 3 credits. Prerequisite: permission of instructor. W. D. Philpot.

An introduction to equipment and methods used in obtaining information about earth resources and the environment from aircraft or satellite. Coverage includes sensors, sensor and ground-data aquisition, data analysis and interpretation, and project design.

CEE 615 Digital Image Processing

Spring. 3 credits. Prerequisites: facility with algebra and trigonometry (e.g., MATH 109) and statistics (e.g., CEE 304 or ARME 310) or permission of instructor. 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 617 Project—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 618 Special Topics—Remote Sensing

On demand. 1–6 credits. W. D. Philpot.

Supervised study in small groups on one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

CEE 620 Water-Resources Systems Engineering

Spring. 3 credits. Prerequisites: CEE 323 and CEE 593. D. P. Loucks.

Development and application of deterministic and stochastic optimization and simulation models for water-resources planning and management. Covers river-basin modeling, including reservoir design and operation, irrigation planning and operation, hydropower-capacity development, flow augmentation, flood control and protection, and water-quality prediction and control.

[CEE 621 Stochastic Hydrology

Spring. 3 credits. Prerequisites: CEE 304 or permission of instructor. Not offered 2003–2004. 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 623 Environmental Quality Systems Engineering

Fall. 3 credits. Prerequisites: MATH 294, optimization, and graduate standing or permission of instructor. Not offered 2003–2004. 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 628 Environmental and Water Resources Systems Analysis Seminar

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 631 Flow and Contaminant Transport Modeling in Groundwater

Spring. 3 credits. Prerequisites: MATH 294 or equivalent, ENGRD 241 or experience in numerical methods and programming, and elementary fluid mechanics. P. L.-F. Liu.

Potential flows and their calculation. Numerical methods include finite difference, finite elements, and boundary elements. 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. The course includes the use of computer programs.

[CEE 632 Hydrology

Spring. 3 credits. Prerequisite: CEE 331. Not offered 2003–2004. 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 633 Flow in Porous Media and Groundwater

Fall. 3 credits. Prerequisite: CEE 331. 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 634 Boundary Layer Meteorology

Fall. 3 credits. Prerequisite: CEE 331 or permission of instructor. 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 635 Small and Finite Amplitude Water Waves

Spring. 3 credits. Not offered 2003–2004. P. L.-F. Liu.

Review of linear and nonlinear theories of ocean waves. Discussions on the applicability of different wave theories to engineering problems.]

CEE 636 Environmental Fluid Mechanics

Spring. 3 credits. E. A. Cowen.

Course 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 637 Experimental Methods in Fluid Dynamics

Spring. 4 credits. Not offered 2003–2004. 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 638 Hydraulics Seminar

Spring. 1 credit. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Staff.

Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

CEE 639 Special Topics in Hydraulics

On demand. 1–6 credits. Staff.

Special topics in fluid mechanics, hydraulic engineering, or hydrology.

CEE 640 Foundation Engineering

Fall. 3 credits. Prerequisite: CEE 341. F. H. Kulhawy.

Course 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 641 Retaining Structures and Slopes

Spring. 3 credits. Prerequisite: CEE 341. T. D. O'Rourke.

Course covers: Earth pressure theories; design of rigid, flexible, braced, tied-back, slurry, 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 644 Environmental Applications of Geotechnical Engineering

Spring. 3 credits. Prerequisite: CEE 341 or equivalent. T. D. O'Rourke.

Covers principles of hydrogeology, contaminant migration, and remediation technologies related to geotechnical and environmental engineering. Emphasis is on 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 649 Special Topics in Geotechnical Engineering

On demand. 1–6 credits. Staff.

Supervised study of special topics not covered in the formal courses.

CEE 653 Water Chemistry for Environmental Engineering

Fall. 3 credits. Prerequisite: 1 semester of college chemistry or permission of instructor. L. W. Lion.

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. The focus of the course is on the mathematical description of chemical reactions relevant to engineered processes and natural systems, and the numerical or graphical solution of these problems.

[CEE 654 Aquatic Chemistry

Spring. 3 credits. Prerequisite: CEE 653 or CHEM 287–288. Not offered 2003–2004. J. J. Bisogni.

Concepts of chemical equilibria applied 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 653.]

CEE 655 Transport, Mixing, and Transformation in the Environment

Fall. 3 credits. Prerequisite: CEE 331. P. L.-F. Liu.

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 659 Environmental Quality Engineering Seminar

Spring. 1 credit. Prerequisite: enrollment as graduate student in environmental engineering. Staff.

Presentation and discussion of current research in environmental engineering.

CEE 671 Random Vibration

Fall. 3 credits. Prerequisites: M&AE 326 and OR&IE 260, or equivalent, and permission of instructor. M. D. Grigoriu.

Review of 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 673 Engineering Analysis
Fall. 3 credits. Prerequisite: instructor permission. Not offered 2003–2004.
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 674 Finite Element Modeling of Civil Infrastructure
Spring. 3 credits. Prerequisites: CEE 371 and either CEE 472 or CEE 778. Staff.
Matrix methods of structural analysis; truss and frame analysis; computer programming of displacement (stiffness) method. Covers: the finite element method as an extension of the displacement method of structural analysis; basic two- and three-dimensional continuum elements. Introduction to nonlinear analysis. Emphasis is on applications in Civil Infrastructure design. The course develops the knowledge base for intelligent usage of finite element programs for structural and geotechnical engineers. Brief exposition of the theory and informed use of commercial codes on more advanced topics: shell elements, material and geometric nonlinearity. Also includes: applications to concrete, steel, and soil structures; solution methods; transient problems.

[CEE 675 Concrete Materials and Construction
Spring. 1–3 credits. Prerequisite: CEE 376 or equivalent. Not offered 2003–2004.
K. C. Hover.
Materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. 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 676 Finite Element Analysis (also M&AE 680 and T&AM 666)
Spring. 3 credits. Prerequisites: T&AM 663 or equivalent. Staff.
For description, see M&AE 680.

[CEE 677 Stochastic Problems in Science and Engineering
Fall. 3 credits. Prerequisites: permission of instructor. Not offered 2003–2004.
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 678 Structural Dynamics and Earthquake Engineering
Spring. 3 credits. M. D. Grigoriu.
Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

CEE 692 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 694 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 710 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 722 Environmental and Water Resources Systems Analysis Research
On demand. 1–6 credits. Prerequisite: permission of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.
Investigations of particular environmental or water resources systems problems.

CEE 729 Special Topics in Environmental or Water Resources Systems Analysis
On demand. 1–6 credits. Staff.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

CEE 735 Research in Hydraulics
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 740 Engineering Behavior of Soils
Fall. 3 credits. Prerequisite: CEE 341. 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 741 Rock Engineering
Fall. 3 credits. Prerequisite: CEE 341 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; and analysis of the stability of rock slopes.

CEE 744 Advanced Foundation Engineering
Spring. 2 credits. Prerequisite: CEE 640. F. H. Kulhawy.
A continuation of CEE 640, 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 745 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 746 Embankment Dam Engineering
Spring. 2 credits. Prerequisites: CEE 641 and 741, or permission of instructor. Not offered 2003–2004. 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 749 Research in Geotechnical Engineering
On demand. 1–6 credits. Staff.
For students who want to pursue a particular geotechnical topic in considerable depth.

CEE 750 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 755 Physical/Chemical Processes
Fall. 3 credits. Prerequisite: previous or concurrent enrollment in CEE 653 or permission of instructor. J. J. Bisogni.
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 756 Biological Processes
Spring. 3 credits. Prerequisites: an introductory course in microbiology and CEE 755, 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. Biokinetic analysis and design of biological treatment process.

CEE 757 Environmental Engineering Process Laboratory I
Fall. 2 credits. Prerequisite: concurrent enrollment in CEE 653 and CEE 755.
J. J. Bisogni and M. L. Weber-Shirk.
Laboratory studies of aquatic chemistry and physical/chemical processes of environmental engineering. Topics include: gravimetric analyses; acids/bases; alkalinity; gas chromatography; UV-visible and atomic absorption spectrophotometry; adsorption; filtration; ion exchange; gas transfer; sedimentation; characterization of reactor mixing regimes; and coagulation.

CEE 758 Biological Processes Laboratory
Spring. 2 credits. Prerequisite: concurrent enrollment in CEE 756. R. Richardson.
Laboratory studies of microbiological phenomena and environmental engineering processes. Topics include microscopy; biochemical and chemical oxygen demand; biological treatability studies; and enumeration of bacteria.

CEE 759 Special Topics in Environmental Engineering
On demand. 1–6 credits. Staff.
Supervised study in special topics not covered in formal courses.

CEE 762 Transportation Research
On demand. 1–6 credits. A. H. Meyburg.
In-depth investigation of a particular transportation planning or engineering problem mutually agreed upon between the student and one or more faculty members.

CEE 764 Special Topics in Transportation
On demand. 1–6 credits. Staff.
Advanced subject matter not covered in depth in other regular courses.

[CEE 770 Engineering Fracture Mechanics
Fall. 3 credits. Prerequisite: CEE 674 or CEE 772 (M&AE 680/T&AM 666) and T&AM 753, or permission of instructor. Offered alternate years. Not offered 2003–2004. 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 773 Structural Reliability
Fall. 3 credits. Prerequisite: permission of instructor. Offered alternate years. Not offered 2003–2004. 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 774 Advanced Structural Concrete
Fall. 3 credits. Prerequisite: undergraduate concrete design course. Staff.
Advanced behavior, analysis, and design of structural concrete with an introduction to prestressing, course project integrating computer simulation and physical experimentation of a design.

[CEE 775 Structural Concrete Systems
Spring. 3 credits. Prerequisite: CEE 774. Not offered 2003–2004. Staff.
Behavior and design of structural concrete building and bridge systems; integration of material, component, and system modeling with structural design; independent study project.]

CEE 776 Advanced Design of Metal Structures
Spring. 3 credits. Prerequisite: CEE 374 or equivalent. T. Pekoz.
Preliminary design of structural systems. Behavior and design of members and connections. Behavior and computer-aided design of building frames.

[CEE 778 Fundamentals of Structural Mechanics
Spring. 4 credits. Corequisite: CEE 673 or T&AM 610. Not offered 2003–2004. K. Papoulia.
Geometric definitions of deformation, rotation, and strain; small-strain theory; concept of stress. Equilibrium and conservation of energy; virtual work. Elements of constitutive theory; elasticity; basic plasticity. Failure criteria for design. Plane stress and plane strain; stress function solutions. Torsion. Several beam theories (shear deformable, dynamic, warping, beam on elastic foundation) based on virtual work. Plate theory and elements of shell theory. Stability. Three lectures and a recitation per week.]

CEE 783 Civil and Environmental Engineering Materials Project
On demand. 1–3 credits. Staff.
Individual projects or reading and study assignments involving engineering materials.

CEE 785 Research in Structural Engineering
On demand. 1–6 credits. Staff.
Pursuit of a branch of structural engineering beyond what is covered in regular courses. Theoretical or experimental investigation of suitable problems.

CEE 786 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 810 Thesis—Remote Sensing
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. W. D. Philpot.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

CEE 820 Thesis—Environmental and Water Resource Systems
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

CEE 830 Thesis—Fluid Mechanics and Hydrology
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis resrarch topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

CEE 840 Thesis—Geotechnical Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

CEE 850 Thesis—Environmental Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

CEE 860 Thesis—Transportation Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

CEE 880 Thesis—Structural Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

COMPUTER SCIENCE

The Department of Computer Science is part of both the College of Arts and Sciences and the College of Engineering.

COM S 099 Fundamental Programming Concepts
Fall, summer. 2 credits. No prerequisites. S-U grades only. Credit cannot be applied toward the Engineering degree. Freshmen only.
This course is designed for students who intend to take COM S 100 but are not adequately prepared for that course. Basic programming concepts and problem analysis are studied. An appropriate high-level programming language is used. Students with previous programming experience and students who do not intend to take COM S 100 should not take this course.

COM S 100 Introduction to Computer Programming
Fall, spring, summer. 4 credits.
An introduction to elementary computer programming concepts. Emphasis is on techniques of problem analysis and the development of algorithms and programs. There are two versions of the course. Both provide adequate preparation for COM S/ENGRD 211. Both versions are not offered every semester.

COM S 100M Introduction to Computer Programming

Corequisite: MATH 111, 191, or equivalent. This version starts with a seven-week introduction to programming in MATLAB. Iteration, functions, and arrays are introduced. During the second seven weeks of the course students examine how these ideas are handled in the object-oriented framework provided by the Java programming language. Throughout the course, examples and assignments are chosen to give the student an appreciation for computational science and engineering. The pace of the course assumes that the student has no prior programming experience.

COM S 100J Introduction to Computer Programming

This course is an introduction to programming using the Java programming language. A two-week unit on MATLAB is included. Topics include algorithms, language concepts, selection, repetition, functions, objects and classes, arrays, strings, and inheritance. Principles of software development and style are emphasized. The course assumes basic high school mathematics (no calculus) but no programming experience.

COM S 101 Introduction to Cognitive Science (also COGST 101, LING 170, and PSYCH 102)

Fall, summer. 3 credits.

For description, see COGST 101.

COM S 113 Introduction to C

Fall, spring. 1 credit. Usually weeks 1–4. Prerequisite: COM S 100 or equivalent programming experience. Credit is granted for both COM S 113 and 213 only if 113 is taken first. S-U grades only.

A brief introduction to the C programming language and standard libraries. Unix accounts are made available for students wishing to use that system for projects, but familiarity with Unix is not required. (Projects may be done using any modern implementation of C.) COM S 213 (C++ Programming) includes much of the material covered in 113. Students planning to take COM S 213 normally do not need to take 113.

COM S 114 Unix Tools

Fall. 1 credit. Usually weeks 5–8. Prerequisite: COM S 100 or equivalent programming experience. S-U grades only.

An introduction to Unix, emphasizing tools for file management, communication, process control, managing your Unix environment, and rudimentary shell scripts. Knowledge of at least one programming language is encouraged. Projects assume no previous knowledge of Unix or expertise in any particular language.

COM S 130 Introductory Web Programming (also CIS 130)

Fall, summer. 3 credits. No prerequisites.

Interactive online media such as the World Wide Web are revolutionizing the way we communicate. This course introduces students having little or no computer background to tools and techniques for creating interactive documents. Questions of both design and technical issues are emphasized. Students must think seriously about digital graphic impact and must learn how to do some relatively simple programming with a scripting language (such as JavaScript). Topics covered include HTML; JavaScript; interaction techniques (elementary DHTML); ways of coping with slow connections; the incorporation of sound, video, and images in web documents; animation techniques (Flash 5); ethics; and e-commerce.

COM S 172 Computation, Information, and Intelligence (also ENGRI 172)

Fall. 3 credits. Prerequisites: some knowledge of calculus.

An introduction to computer science using methods and examples from the field of artificial intelligence. Topics include game playing, search techniques, learning theory, compute-intensive methods, data mining, information retrieval, the web, natural language processing, machine translation, and the Turing test. This is not a programming course; rather, "pencil and paper" problem sets will be assigned. Not open to students who have completed the equivalent of COM S 100.

COM S 201 Cognitive Science in Context Laboratory (also COGST 201 and PSYCH 201)

Spring. 4 credits. Limited to 24 students. Prerequisite: concurrent or prior registration in Introduction to Cognitive Science (PSYCH 102/COGST 101/COM S 101/LING 170/PHIL 191) is suggested but not required. Knowledge of programming languages is not assumed. Fall, B. Halpern and staff; spring, D. Field and staff..

For description, see COGST 201.

COM S 211 Computers and Programming (also ENGRD 211)

Fall, spring, summer. 3 credits. Prerequisite: COM S 100 or an 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.

COM S 212 Java Practicum

Fall, spring, summer. 1 credit. Letter grade only. Pre- or corequisite: COM S/ENGRD 211.

A project course that introduces students to the ways of software engineering using the Java programming language. The course requires the design and implementation of several large programs.

COM S 213 C++ Programming

Spring. 2 credits. Prerequisite: COM S 100 or equivalent programming experience. Students who plan to take COM S 113 and 213 must take 113 first. S-U grades only.

An intermediate-level introduction to the C++ programming language and the C/C++ standard libraries. Topics include basic statements, declarations, and types; stream I/O; user-defined classes and types; derived classes, inheritance, and object-oriented programming; exceptions and templates. Recommended for students who plan to take advanced courses in computer science that require familiarity with C++ or C. Students planning to take COM S 213 normally do not need to take COM S 113; 213 includes most of the material taught in 113.

COM S 214 Advanced UNIX Programming and Tools

Spring. 1 credit. S-U grade only. Prerequisite: COM S 114 or equivalent.

A focus on Unix as a programming environment for people with a basic knowledge of Unix and experience programming in at least one language. Projects cover advanced shell scripts (sh, ksh, csh), Makefiles, programming and debugging tools for C and other languages, and more modern scripting languages such as Perl and Python. Students with little or no experience with Unix should take COM S 114 first.

COM S 215 Introduction to C#

Fall, spring. 1 credit. Prerequisite: COM S/ENGRD 211 or equivalent experience.

Introduces students to building applications in the .NET environment using the C# language.

COM S 230 Intermediate Web Design (also CIS 230)

Spring. 3 credits. Prerequisite: COM S 130 or equivalent.

Web programming requires the cooperation of two machines: the one in front of the viewer (client) and the one delivering the content (server). COM S 130 concentrates almost exclusively on the client side. The main emphasis in COM S 230 is learning about server side processing. Students begin by looking at interactions with databases, learning about querying both on paper and via SQL, and then, through a succession of projects, learn how to apply this understanding to the creation of an interactive data-driven site via the use of an integrated web site development tool such as ColdFusion. Also considered are techniques to enhance security, privacy, and reliability and ways of incorporating other programs. Toward the end of the course, students are shown how these development tools are working. Design issues are emphasized. A major component of the course is the creation of a substantial web site.

COM S 280 Discrete Structures

Fall, spring. 4 credits. Pre- or corequisite: COM S/ENGRD 211 or permission of instructor.

Covers mathematical aspects of programming and computing. Topics are chosen from the following: mathematical induction; logical proof; propositional and predicate calculus; combinatorics and discrete mathematics covering manipulation of sums, recurrence relations, and generating-function techniques; basic number theory; sets, functions, and relations; partially ordered sets; graphs; and algebraic structures.

COM S 312 Data Structures and Functional Programming

Fall, spring. 4 credits. Prerequisite: COM S 211/212 or equivalent programming experience. Should not be taken concurrently with COM S 314.

An advanced programming course that emphasizes functional programming techniques and data structures. Programming topics include recursive and higher-order procedures, models of programming language evaluation and compilation, type systems, and polymorphism. Data structures and algorithms covered include graph algorithms, balanced trees, memory heaps, and garbage collection. Also covered are techniques for analyzing program performance and correctness.

COM S 314 Computer Organization (also ECE 314)

Fall, spring. 4 credits. Prerequisite: COM S 211; COM S 312 or ENGRD 230 are recommended but not required. Should not be taken concurrently with COM S 312.

Basic computer organization. Topics include performance metrics, data formats, instruction sets, addressing modes, computer arithmetic, datapath design, memory hierarchies including caches and virtual memory, I/O devices, and bus-based I/O systems. Students learn assembly language programming and design a simple pipelined processor.

COM S 321 Numerical Methods in Computational Molecular Biology (also BIO BM 321 and ENGRD 321)

Fall. 3 credits. Prerequisites: at least one course in calculus, such as MATH 106, 111, or 191 and a course in linear algebra, such as MATH 221 or 294 or BTRY 417. COM S 100 or equivalent and some familiarity with iteration, arrays, and procedures.

An introduction to numerical computing using MATLAB organized around five applications: the analysis of protein shapes, dynamics, protein folding, score functions, and field equations. Students become adept at plotting, linear equation solving, least squares fitting, and cubic spline interpolation. More advanced problem-solving techniques that involve eigenvalue analysis, the solution of ordinary and partial differential equations, linear programming, and nonlinear minimization will also be treated. The goal of the course is to develop a practical computational expertise with MATLAB and to build mathematical intuition for the problems of molecular biology. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, or 421.

COM S 322 Introduction to Scientific Computation (also ENGRD 322)

Spring, summer. 3 credits. Prerequisites: COM S 100 and (MATH 222 or MATH 294).

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. The MATLAB computing environment is used. Vectorization, efficiency, reliability, and stability are stressed. Includes special lectures on parallel computation. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, or 421.

COM S 324 Computational Linguistics (also COGST 424, LING 424)

Fall, spring. 4 credits. Prerequisites: LING 203; labs involve work in the Unix environment; COM S 114 recommended.

For description, see LING 424.

COM S 330 Applied Database Systems (also CIS 330)

Spring. 3 credits. Prerequisite: COM S 211/ENGRD 211. COM S majors may use only one of the following toward their degree: CIS/COM S 330 or COM S 433.

An introduction to modern database systems and three-tier application development using database systems. Concepts covered include the relational model, query languages, data modeling, database tuning, three-tier architectures, Internet data formats and query languages, server- and client-side technologies, decision support systems, and an introduction to data mining. The course is targeted at users of database systems and at application development using database systems and includes several programming projects comprising the design and implementation of a data base–backed web site.

COM S 381 Introduction to Theory of Computing

Fall, summer. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and COM S 481. Corrective transfers between COM S 381 and COM S 481 (in either direction) are encouraged during the first few weeks of instruction.

An introduction to the modern theory of computing: automata theory, formal languages, and effective computability.

COM S 411 Programming Languages

Fall. 4 credits. Prerequisite: COM S 312 or permission of instructor.

An introduction to the theory, design, and implementation of programming languages. Topics include operational semantics, type systems, higher-order function, scope, lambda calculus, laziness, exceptions, side effects, continuations, objects, and modules. Also discussed are logic programming, concurrency, and distributed and persistent programming.

COM S 412 Introduction to Compilers

Spring. 3 credits. Prerequisites: COM S 312 (or permission of instructor) and COM S 314. Corequisite: COM S 413.

An introduction to the specification and implementation of modern compilers. Topics covered include lexical scanning, parsing, type checking, code generation and translation, an introduction to optimization, and the implementation of modern programming languages. The course entails a substantial compiler implementation project.

COM S 413 Practicum in Compilers

Spring. 2 credits. Corequisite: COM S 412.

A compiler implementation project related to COM S 412.

COM S 414 Systems Programming and Operating Systems

Fall, spring, summer. 3 credits. Prerequisite: COM S 211, 212, 312 (or permission of instructor), and 314. Corequisite: COM S 415 in spring only.

An introduction to the logical design of systems programs, with emphasis on multiprogrammed operating systems. Topics include process synchronization, deadlock, memory management, input-output methods, information sharing, protection and security, and file systems. The impact of network and distributed computing environments on operating systems is also discussed.

COM S 415 Practicum in Operating Systems

Fall, spring. 2 credits. Corequisite: COM S 414.

The practical aspects of operating systems are studied through the design and implementation of an operating system kernel that supports multiprogramming, virtual memory, and various input-output devices. All the programming for the project is in a high-level language.

COM S 421 Numerical Analysis

Fall. 4 credits. Prerequisites: MATH 294 or equivalent, one additional mathematics course numbered 300 or above, and knowledge of programming.

Modern algorithms for systems of linear equations, systems of nonlinear equations, numerical optimization, and numerical solution of differential equations. Some discussion of methods suitable for parallel computation. This course requires more mathematical sophistication than COM S 322. COM S majors and minors may use only one of the following toward their degree: COM S 321, 322, or 421.

COM S 426 Introduction to Computational Biology

Fall. 3 credits. Prerequisites: COM S/ENGRD 211, COM S 280.

Computational biology is a relatively new field that is rooted in two different disciplines: computer science and molecular biology. It is concerned with the study of biological systems and phenomena, in search for explanations, rules, patterns, and regularities. The focus of this course is the set of algorithms, tools, and models used today to analyze biological data and recover and discover hidden information. These tools can be used to predict the function of new genes, discover hidden motifs that are biologically significant, study evolutionary processes, better understand cellular "computations," and aid in the development of new therapeutic agents for treatment of various diseases. Some of the topics covered are sequence analysis (alignment, multiple sequence alignment), motif detection, phylogenetic trees, secondary structure prediction, Hidden Markov Models, and analysis of gene expression data.

This course is intended mostly for students in the computational sciences because it focuses on algorithms and mathematical models. No knowledge of biology is needed (the course starts with a brief overview of the basic entities and the central dogma of molecular biology, and other relevant terms are introduced as needed).

COM S 427 Practicum in Computational Biology

Fall. 2 credits. Pre- or corequisite: COM S 426.

In this course, students develop a system or an application to analyze biological data. Possible applications are a database system to manipulate multiple data types, a learning system to detect hidden patterns in massive biological data sets, a software suite for sequence comparison or analysis of gene expression data, etc.

COM S 430 Information Discovery (also CIS 430)

Fall. 3 credits. Prerequisite: COM S 211 or equivalent.

This course studies the methods used to search for and discover information in large-scale systems. The emphasis is on information retrieval applied to textual materials, but there is some discussion of other formats. The course includes techniques for searching, browsing, and filtering information and the use of classification systems and thesauruses. The techniques are illustrated with examples from web searching and digital libraries.

COM S 431 Web Information Systems (also CIS 431; formerly CIS/COM S 502)

Spring. 3 credits. Prerequisites: COM S 211 and some familiarity with the technology of web sites.

This course examines the architecture of web information systems such as distributed digital libraries and electronic publishing systems. Many of the topics presented in the course are the subject of current research and development at Cornell, other universities, and in standards organizations such as the World Wide Web Consortium. Course content mixes exploration of current tools for building web information systems such XML, XSLT, and RDF with broader concepts such as techniques for knowledge representation and description, object models for content representation, and legal and economic impacts of web information. A theme that runs throughout the course is the relationship between traditional information environments, exemplified by libraries, and the distributed information environment of the web.

COM S 432 Introduction to Database Systems

Fall. 3 credits. Prerequisites: COM S 312, or 211/212, and permission of instructor. Recommended: COM S 213 and strong programming skills in C or C++.

An introduction to modern relational database systems. Concepts covered include storage structures, access methods, query languages, query processing and optimization, transaction processing, and database design theory. The course primarily covers the internals of database systems and includes four large programming assignments in C++.

COM S 433 Practicum in Database Systems

Fall. 2 credits. Corequisite: COM S 432. COM S majors may use only one of the following toward their degree: CIS/COM S 330 or COM S 433.

An introduction to building web-database applications. Students implement a small e-commerce system using Active Server Pages, Java Server Pages, Cookies, and Servlets. The practicum also introduces technologies such as XML/XPath/XSLT and WAP.

COM S 465 Computer Graphics I (also ARCH 374)

Fall. 3 credits. Prerequisite: COM S/ENGRD 211. May not be taken after completion of COM S 417.

An introduction to the principles of computer graphics in two and three dimensions. Topics include human visual perception, digital images, rasterization and anti-aliasing, 2D and 3D affine geometry, perspective and 3D viewing, spline curves, elementary 3D surface modeling, and ray tracing. Homework assignments require some programming.

COM S 467 Computer Graphics II

Spring. 3 credits. Prerequisite: COM S 465.

This course covers the principles of computer graphics in detail. A wide variety of topics are covered, including 3D transformations, the hardware graphics pipeline, advanced texturing and shading, visual perception and color science, rendering algorithms including global illumination, animation, user interfaces, visualization, and 3D surface modeling.

COM S 468 Computer Graphics Practicum

Spring. 2 credits. Prerequisite: COM S 465. Co-requisite: COM S 467.

This course provides COM S 467 students with hands-on experience in computer graphics programming. Programming assignments cover 3D transformations, modeling, shading, rendering, animation, and user interfaces. The course uses Java, OpenGL, and Cg for code development.

COM S 472 Foundations of Artificial Intelligence

Fall. 3 credits. Prerequisites: COM S/ENGRD 211 and COM S 280 (or equivalent).

A challenging introduction to the major subareas and current research directions in artificial intelligence. Topics include knowledge representation, heuristic search, problem solving, natural-language processing, game-playing, logic and deduction, planning, and machine learning.

COM S 473 Practicum in Artificial Intelligence

Fall. 2 credits. Corequisite: COM S 472.

Project portion of COM S 472. Topics include knowledge representation systems, search procedures, game-playing, automated reasoning, concept learning, reinforcement learning, neural nets, genetic algorithms, planning, and truth maintenance.

[COM S 474 Introduction to Natural Language Processing (also COGST 474, LING 474)

Fall. 4 credits. Prerequisites: COM S 211. Not offered every year.]

COM S 478 Machine Learning

Spring. 4 credits. Prerequisites: COM S 280, 312, and basic knowledge of linear algebra and probability theory.

Learning and classifying are two of our basic abilities. Machine learning is concerned with the question of how to train computers to learn from experience, to adapt and make decisions accordingly. This course introduces the set of techniques and algorithms that constitute machine learning as of today, including inductive inference of decision trees, the parametric-based Bayesian learning approach, Bayesian belief networks and Hidden Markov Models, non-parametric methods, discriminent functions and support vector machines, neural networks, stochastic methods such as genetic algorithms, unsupervised learning and clustering, and other issues in the theory of machine learning. These techniques are used today to automate procedures that were previously performed by humans as well as to explore untouched domains of science.

COM S 481 Introduction to Theory of Computing

Fall. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and 481. Corrective transfers between COM S 481 and 381 (in either direction) are encouraged during the first few weeks of instruction.

A faster-moving and deeper version of COM S 381.

COM S 482 Introduction to Analysis of Algorithms

Spring, summer. 4 credits. Prerequisites: COM S 280, 312, and either 381 or 481, or permission of instructor.

Techniques used in the creation and analysis of algorithms. Combinatorial algorithms, computational complexity, NP-completeness, and intractable problems.

COM S 483 Quantum Computation (also PHYS 481 and 681)

Spring. 2 credits. Prerequisite: familiarity with the theory of vector spaces over the complex numbers. Not offered every year.

For description, see PHYS 481.

COM S 486 Applied Logic (also MATH 486)

Fall or spring. 4 credits. Prerequisites: MATH 222 or 294, COM S 280 or equivalent (such as MATH 332, 432, 434, 481), and some additional course in mathematics or theoretical computer science.

Propositional and predicate logic, compactness and completeness by tableaux, natural deduction, and resolution. Equational logic. Herbrand Universes and unification. Rewrite rules and equational logic, Knuth-Bendix method, and the congruence-closure algorithm and lambda-calculus reduction strategies. Topics in Prolog, LISP, ML, or Nuprl. Applications to expert systems and program verification.

COM S 490 Independent Reading and Research

Fall, spring. 1–4 credits.

Independent reading and research for undergraduates.

COM S 501 Software Engineering

Spring. 4 credits. Prerequisite: COM S 211 or equivalent experience programming in Java or C++.

An introduction to the practical problems of specifying, designing, and building large, reliable software systems. Students work in teams on projects for real clients. This work includes a feasibility study, requirements analysis, object-oriented design, implementation, testing, and delivery to the client. Additional topics covered in lectures include professionalism, project management, and the legal framework for software development.

COM S 504 Applied Systems Engineering I (also CEE 504, ECE 512, M&AE 591, OR&IE 512, SYSEN 510)

Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor.

For description, see M&AE 591.

COM S 505 Applied Systems Engineering II (also CEE 505, ECE 513, M&AE 592, OR&IE 513, SYSEN 520)

Spring. 3 credits. Prerequisite: Applied System Engineering I (CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512).

For description, see M&AE 592.

COM S 513 System Security

Spring. 4 credits. Prerequisites: COM S 414 or 519 and familiarity with JAVA programming language.

This course discusses security and survivability for computers and communications networks. The course includes discussions of policy issues (e.g., the national debates on cryptography policy) as well as the discussions of the technical alternatives for implementing the properties that comprise "trustworthiness" in a computing system. Mechanisms for authorization and authentication as well as cryptographic protocols are covered.

COM S 514 Intermediate Computer Systems

Fall. 4 credits. Prerequisites: COM S 414 or permission of instructor.

This course focuses on practical issues in designing and implementing distributed software. Topics vary depending upon instructor. Recent offerings have covered object-oriented software development methodologies and tools, distributed computing, fault-tolerant systems, and network operating systems or databases. Students undertake a substantial software project. Many students obtain additional project credit by coregistering in COM S 490, 515, or 790.

COM S 519 Computer Networks

Spring. 4 credits. Prerequisites: COM S 314 or permission of instructor. Not offered every year.

Introduction to computer networks with an emphasis on evolving Internet standards. Detailed introduction to networking protocols for reliable data transfer, flow control, congestion control, naming and addressing, routing, error control, and multiple access. Fundamentals of layered protocols and techniques for protocol design and implementation. The course is project-oriented and requires substantial programming experience.

COM S 522 Computational Tools and Methods for Finance

Spring. 4 credits. Prerequisites: programming experience (e.g., C, FORTRAN, or MATLAB), some knowledge of numerical methods, especially numerical linear algebra. Not offered every year.

This course provides a hands-on introduction to computational methods and tools used in finance. Students study both the underlying methods and efficient implementation. The MATLAB Financial Toolbox, along with additional MATLAB tools, are used extensively. The underlying numerical techniques discussed include: nonlinear least-squares procedures (regression), basic linear algebra, linear and nonlinear optimization, finite-difference methods for PDEs, quadratic programming (and linear complementarity problems), and specialized tree (and lattice) evaluation methods.

COM S 572 Heuristic Methods for Optimization (also CEE 509)

Spring. 3 or 4 credits. Prerequisites: COM S/ENGRD 211 or 322 or CEE/ENGRD 241, or graduate standing, or permission of instructor. Not offered every year.

This course describes a variety of heuristic search methods including simulated annealing, tabu search, genetic algorithms, derandomized evolution strategy, random walk, and direct search algorithms. Algorithms are used to find values of discrete and/or continuous variables arising in optimization and model fitting. Applications are discussed in a range of areas including some of the following: artificial intelligence, scheduling, protein folding, economic planning, water quality protection, telecommunications, and robotics. The advantages and disadvantages of heuristic search methods for both serial and parallel computation are discussed in comparison to other optimization algorithms.

[COM S 574 Language Technologies

Fall. 3 credits. Prerequisites: COM S 472 or 478 or 578 or the equivalent. Not offered every year.

This course studies computational techniques for large-scale text-processing applications including: information retrieval, text classification, information extraction, document clustering, document ranking, summarization, topic detection and tracking, and question answering. The course focuses on statistical and machine learning approaches to these natural language processing tasks as well as methods for their empirical evaluation.]

COM S 578 Empirical Methods in Machine Learning and Data Mining

Fall. 4 credits. Prerequisites: COM S 280 and 312 or equivalent.

This implementation-oriented course presents a broad introduction to current algorithms and approaches in machine learning, knowledge discovery, and data mining and their application to real-world learning and decision-making tasks. The course also covers experimental methods for comparing learning algorithms, for understanding and explaining their differences, and for exploring the conditions under which each is most appropriate.

[COM S 601 System Concepts

Fall. 3 credits. Prerequisites: open to students enrolled in the COM S Ph.D. program. Not offered every year.]

COM S 611 Advanced Programming Languages

Fall. 4 credits. Graduate standing or permission of instructor.

A study of programming paradigms: functional, imperative, concurrent, and logic programming. Models of programming languages, including the lambda calculus. Type systems, polymorphism, modules, and other object-oriented constructs. Program transformations, programming logic, and applications to programming methodology.

COM S 612 Compiler Design for High-Performance Architectures

Spring. 4 credits. Prerequisites: COM S 314 and 412 or permission of instructor.

Compiler design for pipelined and parallel architectures. Program analysis: data and control dependencies, dataflow analysis, efficient solution of dataflow equations, dependence tests, solution of Diophantine equations. Architecture and code generation for instruction-level parallel (ILP) processors: pipelined, VLIW and superscalar architectures, code reorganization and software pipelining. Architecture and code generation for multiprocessors: shared- and distributed-memory architectures, latency tolerance and avoidance, loop transformations to enhance parallelism and locality of reference.

[COM S 613 Concurrent Programming

Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor. Not offered every year.]

COM S 614 Advanced Systems

Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor.

An advanced course in systems, emphasizing contemporary research in distributed systems. Topics may include communication protocols, consistency in distributed systems, fault-tolerance, knowledge and knowledge-based protocols, performance, scheduling, concurrency control, and authentication and security issues.

COM S 615 Adaptive Systems

Fall. 4 credits. Prerequisites: COM S 614 recommended.

This course broadly examines self-organization in distributed systems, with particular emphasis on peer-to-peer and mobile ad hoc networks. Students read recent research papers on proactive, reactive and hybrid routing protocols for ad hoc networks, system support for mobility, peer-to-peer systems and their applications.

COM S 621 Matrix Computations

Fall. 4 credits. Prerequisites: MATH 411 and 431 or permission of instructor.

Stable and efficient algorithms for linear equations, least squares, and eigenvalue problems. Direct and iterative methods are considered. The MATLAB system is used extensively.

[COM S 622 Numerical Optimization and Nonlinear Algebraic Equations

Spring. 4 credits. Prerequisite: COM S 621. Offered odd-numbered years only.

Modern algorithms for the numerical solution of multidimensional optimization problems and simultaneous nonlinear algebraic equations. Emphasis is on efficient, stable, and reliable numerical techniques with strong global convergence properties: quasi-Newton methods, modified Newton algorithms, and trust-region procedures. Special topics may include large-scale optimization, quadratic programming, and numerical approximation.]

COM S 624 Numerical Solution of Differential Equations

Spring. 4 credits. Prerequisites: previous exposure to numerical analysis (e.g., COM S 421 or 621) and differential equations, and knowledge of MATLAB. Offered in even-numbered years.

Finite difference methods for the solution of ordinary and partial differential equations. A fast-moving course that begins with a three-week survey of numerical methods for ODEs, then moves on to Fourier analysis and methods for PDEs, especially parabolic and hyperbolic equations. Other topics covered include numerical stability, finite element methods, Hamiltonian problems, and computational issues such as mesh generation and sparse matrix computation for PDES.

COM S 626 Computational Molecular Biology

Spring. 4 credits. Prerequisites: familiarity with linear programming, numerical solutions of ordinary differential equations, and nonlinear optimization methods.

Problems and algorithms in computational molecular biology. Topics include sequences (alignment, scoring functions, complexity of searches and alignment, secondary structure prediction, families, and function), the protein folding problem (lattice models, lattice searches, the HP model, chemical potentials, statistical potentials, funnels, complexity and model verification, global optimization, homology, threading), and the dynamics of complex biosystems (the Molecular Dynamics method, long-range forces, statistics of flexible systems, reduced models).

COM S 627 Computational Biology: The Machine Learning Approach

Spring. 4 credits. Prerequisites: COM S 426 or 626 and COM S 478 or 578 or permission of instructor.

This is a graduate-level course in computational biology that focuses on machine learning models and their application to computational problems in biology. Some topics covered are supervised (Support Vector Machines, Hidden Markov Models, deterministic and probabilistic suffix trees) and unsupervised (embedding, PCA, ICA, clustering) learning in computational biology, advanced statistical analysis of sequences, analysis of microarrays, and modeling of complex systems (Bayesian Belief Networks, DEA).

COM S 630 Representing and Accessing Digital Information (also CIS 630)

Fall. 4 credits. Prerequisites: COM S 472 or 478 or 578 or the equivalent.

This course covers the representation, organization, and access of digital information with an emphasis on textual information. Topics include structured and semistructured data, information retrieval, natural language processing, and machine learning, with links to work in databases, data mining, and computational linguistics.

COM S 632 Advanced Database Systems

Spring. 4 credits. Prerequisite: COM S 432/433 or permission of instructor.

A variety of advanced issues ranging from transaction management to query processing to data mining. Involves extensive paper reading and discussion. Development of a term project with research content is required.

COM S 664 Machine Vision

Fall. 4 credits. Prerequisites: undergraduate-level understanding of algorithms and MATH 221 or equivalent.

An introduction to computer vision, with an emphasis on discrete optimization algorithms and on applications in medical imaging. The following topics are covered: edge detection, image segmentation, stereopsis, motion and optical flow, active contours, and the Hausdorff distance. Students are required to implement several of the algorithms covered in the course and complete a final project.

COM S 665 Advanced Rendering

Fall or spring. 4 credits. Prerequisites: COM S 465 and 467 or equivalent and an undergraduate-level understanding of algorithms, probability and statistics, vector calculus, and programming. Offered fall 2003.

This course covers advanced topics in realistic rendering with a focus on fast/interactive techniques. Topics include light transport and global illumination, Monte-Carlo ray tracing and radiosity, hardware rendering, and image-based rendering.

COM S 667 Physically Based Rendering

Fall or spring. 4 credits. Prerequisites: COM S 465 and 467 or equivalent and an undergraduate-level understanding of algorithms, programming, and vector calculus. Offered spring 2004.

An advanced course in realistic image synthesis, focusing on the computation of physically accurate images. Topics include radiometry; light transport and global illumination; rendering with participating media; advanced models for material properties; and physical measurement of light sources, images, and materials.

COM S 671 Introduction to Automated Reasoning

Fall. 4 credits. Prerequisite: (COM S 611 and graduate standing) or permission of instructor.

Topics in modern logic needed to understand and use automated reasoning systems such as HOL, Nuprl, and PVS. Special emphasis is on type theory and logic and on tactic-oriented theorem proving.

COM S 672 Advanced Artificial Intelligence

Spring. 4 credits. Prerequisites: COM S 472 or permission of instructor.

Artificial intelligence (AI) provides many computational challenges. This course covers a variety of areas in AI, including knowledge representation, automated reasoning, learning, game-playing, and planning, with an emphasis on computational issues. Specific topics include stochastic reasoning and search procedures, properties of problem encodings, issues of syntax and semantics in knowledge representation, constraint satisfaction methods and search procedures, and critically constrained problems and their relation to phase-transition phenomena. In addition, connections between artificial intelligence and other fields, such as statistical physics, operations research, and cognitive science are explored.

COM S 674 Natural Language Processing

Spring. 3 credits. Prerequisites: COM S 472 or permission of instructor. COM S 474 is NOT a prerequisite. Not offered every year.

This course presents a graduate-level introduction to natural language processing, the primary concern of which is the study of human language use from a computational perspective. The course covers syntactic analysis, semantic interpretation, and discourse processing, examining both symbolic and statistical approaches. Possible topics include information extraction, natural language generation, memory models, ambiguity resolution, finite-state methods, mildly context-sensitive formalisms, deductive approaches to interpretation, machine translation, and machine learning of natural language.

COM S 676 Reasoning about Knowledge

Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic.

Knowledge plays a crucial role in distributed systems, game theory, and artificial intelligence. Material examines formalizing reasoning about knowledge and the extent to which knowledge is applicable to those areas. Issues include common knowledge, knowledge-based programs, applying knowledge to analyzing distributed systems, attainable states of knowledge, modeling resource-bounded reasoning, and connections to game theory.

[COM S 677 Reasoning about Uncertainty

Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic. Not offered 2003–2004.

Examines formalizing reasoning about and representing uncertainty, using formal logical approaches as a basis. Topics: logics of probability, combining knowledge and probability, probability and adversaries, conditional logics of normality, Bayesian networks, qualitative approaches to uncertainty, going from statistical information to degrees of belief, and decision theory.]

COM S 678 Advanced Topics in Machine Learning

Spring. 4 credits. Prerequisites: COM S 478 or equivalent, or COM S 578 or equivalent, or permission of instructor.

This course extends and complements COM S 478 and COM S 578, giving in-depth coverage of new and advanced methods in machine learning. In particular, we connect to open research questions in machine learning, giving starting points for future work. The content of the course reflects an equal balance between learning theory and practical machine learning, making an emphasis on approaches with practical relevance. Topics include support vector machines, clustering, Bayes nets, boosting, model selection, learning orderings, and inductive transfer.

COM S 681 Analysis of Algorithms

Fall. 4 credits. Prerequisite: COM S 482 or graduate standing.

Methodology for developing efficient algorithms, primarily for graph theoretic problems. Understanding of the inherent complexity of natural problems via polynomial-time algorithms, randomized algorithms, NP-completeness, and randomized reducibilities. Also covers topics such as parallel algorithms and efficient data structures.

COM S 682 Theory of Computing

Spring. 4 credits. Prerequisite: COM S 381 or 481 and COM S 482 or 681 or permission of instructor.

Advanced treatment of theory of computation, computational-complexity theory, and other topics in computing theory.

[COM S 683 Advanced Design and Analysis of Algorithms

Spring. 4 credits. Prerequisites: COM S 681 or permission of instructor. Not offered every year.]

[COM S 684 Approximation and Network Algorithms

Fall. 4 credits. Prerequisites: COM S 681 or permission of instructor. Not offered every year.]

COM S 685 The Structure of Information Networks (also CIS 685)

Spring. 4 credits. Prerequisite: COM S 482.

Information networks such as the world wide web are characterized by the interplay between heterogeneous content and a complex underlying link structure. This course covers recent research on algorithms for analyzing such networks and models that abstract their basic properties. Topics include combinatorial and probabilistic techniques for link analysis, centralized and decentralized search algorithms, generative models for networks, and connections with work in the areas of social networks and citation analysis.

[COM S 686 Logics of Programs

Spring. 4 credits. Prerequisites: COM S 481, 682, and MATH 481 or MATH/COM S 486. Not offered every year.]

COM S 709 Computer Science Colloquium
Fall, spring. 1 credit. S-U grades only. For staff, visitors, and graduate students interested in computer science.
A weekly meeting for the discussion and study of important topics in the field.

COM S 711 Seminar in Advanced Programming Languages
Fall, spring. 3 credits.

COM S 713 Seminar in Systems and Methodology
Fall, spring. 4 credits. Prerequisites: a graduate course employing formal reasoning such as COM S 611, 613, 671, a logic course, or permission of instructor. Not offered every year.
Discussion of contemporary issues in the design and analysis of computing systems. Emphasis is on the proper use of rigor, models, and formalism.

COM S 715 Seminar in Programming Refinement Logics
Fall, spring. 4 credits. Prerequisite: permission of instructor.
Topics in programming logics, possibly including type theory, constructive logic, decision procedures, heuristic methods, extraction of code from proofs, and the design of proof-development and problem-solving systems.

COM S 717 Topics in Parallel Architectures
Fall. 4 credits. Prerequisite: COM S 612 or permission of instructor. Not offered every year.
Covers topics in parallel computers. Material includes: architectures of parallel computers, parallelizing compilers, operating systems for parallel computers, and languages (functional and logic-programming languages) designed for parallel computation.

COM S 719 Seminar in Programming Languages
Fall, spring. 4 credits. Prerequisite: COM S 611 or permission of instructor. S-U grades only.

COM S 721 Topics in Numerical Analysis
Fall, spring. 4 credits. Prerequisite: COM S 621 or 622 or permission of instructor. Not offered every year; semester TBA.
Topics are chosen at instructor's discretion.

COM S 726 Problems and Perspectives in Computational Molecular Biology (also PL BR 726)
Fall, spring. 1 credit. S-U grades only.
This is a weekly seminar series discussing timely topics in computational molecular biology. The course addresses methodological approaches to sequence and structure analysis, function prediction, study of evolutionary relationships, and analysis of large biological systems. Statistical and deterministic computational approaches are covered, and specific and detailed biological examples are discussed. In each topic, we select one or two representative papers that made significant advances in this field. The lectures are given by faculty and students. The seminar is open to all from the life sciences, computational sciences, and physical sciences. We try to bridge these disciplines by pairing students/faculty from complementary backgrounds.

COM S 732 Seminar in Database Systems
Fall, spring. 4 credits. S-U grades only.

[COM S 750 Evolutionary Computation and Design Automation (also CIS 750, MAE 650)
Fall. 4 credits. Prerequisite: programming experience or permission of instructor. Not offered every year.]

[COM S 751 Media Research and Critical Design (also CIS 751)
Fall. 4 credits. Prerequisites: graduate standing in COM S or equivalent ability to read technical research papers. Contact instructor if unsure of qualifications. Not offered every year.]

[COM S 752 Seminar on Scholarly Information Architecture (also CIS 752)
Fall. 3 credits. Prerequisite: concurrent enrollment in COM S 502 or equivalent experience. S-U grades only. Not offered every year.]

COM S 754 Systems Research Seminar
Fall, spring. 1 credit. S-U grades only.

COM S 772 Seminar in Artificial Intelligence
Fall, spring. 4 credits. Prerequisites: permission of instructor. S-U grades only.

COM S 775 Seminar in Natural Language Understanding
Fall, spring. 2 credits.
Informal weekly seminar in which current topics in natural language understanding and computational linguistics are discussed.

COM S 786 Introduction to Kleene Algebra
Spring. 4 credits. Prerequisites: COM S 481 required; COM S 482 or 681, COM S 682, elementary logic (MATH 481 or 681), algebra (MATH 432) recommended.
Kleene algebra is an algebraic system that axiomatically captures the properties of a natural class of structures arising in logic and computer science. It has appeared in various guises in relational algebra, semantics and logics of programs, automata and formal language theory, and the design and analysis of algorithms. In this course, we review the history of the development of Kleene algebra and Kleene algebra with tests (Kleene/Boolean algebra). We study models, compare axiomatizations, and derive completeness, expressiveness, and complexity results. We also discuss various applications in program schematology, program verification, compiler optimization, and programming language semantics and logic.

COM S 789 Seminar in Theory of Algorithms and Computing
Fall, spring. 4 credits. Prerequisite: permission of instructor. S-U grades only.

COM S 790 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. Letter grade only.
Independent research or Master of Engineering project.

COM S 990 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only. Doctoral research.

EARTH AND ATMOSPHERIC SCIENCES

Courses

For complete course descriptions, see the Earth and Atmospheric Sciences listing in the College of Arts and Sciences or the College of Agriculture and Life Sciences section.

EAS 101 Introductory Geological Sciences
Fall, spring. 3 credits. Staff.

EAS 102 Evolution of the Earth and Life (also offered as BIO G 170)
Spring. 3 credits. J. L. Cisne.

EAS 107 How the Earth Works
Fall. 1 credit. J. L. Cisne.

EAS 108 Earth in the News
Summer. 3 credits. S. L. Losh.

EAS 109 Dinosaurs
Fall. 1 credit. J. L. Cisne.

EAS 111 To Know the Earth and Build a Habitable Planet
Fall. 3 credits. J. M. Bird.

EAS 122 Earthquake! (also ENGRI 122)
Spring. 3 credits. L. D. Brown.
This is a course in the Introduction to Engineering series. For description, see ENGRI 122.

EAS 131 Basic Principles of Meteorology
Fall. 3 credits. M. W. Wysocki.
The one-credit laboratory for this course is EAS 133.

EAS 133 Basic Meteorology Lab
Fall. 1 credit. Laboratory. Prerequisite: concurrent enrollment in EAS 131. M. W. Wysocki.
Laboratory course covering topics presented in EAS 131. This course is required for atmospheric science majors, but is optional for other students taking EAS 131.

EAS 150 Introduction to Fortran Programming
Fall. 3 credits. M. W. Wysocki.

EAS 154 The Sea: An Introduction to Oceanography (also BIOEE 154)
Spring, summer. 3 credits. Lecture. Spring: C. H. Greene, W. M. White; summer: B. C. Monger. The optional one-credit laboratory for this course is EAS 155/BIOEE 155.

EAS 155 The Sea: An Introduction to Oceanography (also BIOEE 155)
Spring. 1 credit. Laboratory. Prerequisite: Concurrent enrollment in EAS 154. C. H. Greene.
Laboratory course covering topics presented in EAS 154.

EAS 200 Art, Archaeology, and Analysis (also ENGRI 185, or MS&E 285)
Spring. 3 credits. R. W. Kay.
This is a course in the Introduction to Engineering series. For description, see ENGRI 185.

EAS 201 Introduction to the Physics and Chemistry of the Earth (also ENGRD 201)
Fall. 3 credits. Prerequisites: PHYS 112 or 207. L. M. Cathles.

EAS 210 Introduction to Field Methods in Geological Sciences
Fall. 3 credits. Prerequisites: EAS 101 or 201, or permission of instructor. 1 lecture, Saturday field trips. R. W. Allmendinger.

EAS 213 Marine and Coastal Geology
Summer. 4 credits. Prerequisite: an introductory course in geology or ecology or permission of instructor. Staff.

EAS 250 Meteorological Observations and Instruments
Spring. 3 credits. Prerequisite: EAS 131. M. W. Wysocki.

EAS 260 Soil Science (also CSS 260)
Fall. 4 credits. S. J. Riha.

EAS 268 Climate and Global Warming
Spring. 3 credits. A. T. DeGaetano.

EAS 296 Forecast Competition
Fall and spring. 1 credit. S-U grades only. Prerequisite: sophomore undergraduate standing in atmospheric science, or permission of instructor. D. S. Wilks.

EAS 302 Evolution of the Earth System
Spring. 4 credits. Prerequisites: MATH 112 or 192 and CHEM 207 or equivalent. W. M. White, W. D. Allmon, B. L. Isacks.

EAS 315 Geomorphology
Fall. 4 credits. Prerequisite: one course in geology, hydrology, or soil science. B. L. Isacks.

EAS 321 Introduction to Biogeochemistry (also NTRES 321)
Fall. 4 credits. Prerequisites: CHEM 207, MATH 112, plus a course in biology and/or geology. L. A. Derry, J. Yavitt.

EAS 326 Structural Geology
Spring. 4 credits. Prerequisite: MATH 112, EAS 101, or 201, or permission of instructor. One weekend field trip. R. W. Allmendinger.

EAS 331 Climate Dynamics (also ASTRO 331)
Fall. 4 credits. Prerequisite: two semesters of calculus and one semester of physics. K. H. Cook, P. J. Gierasch.

EAS 334 Microclimatology
Spring. 3 credits. Prerequisite: a course in physics. Offered alternate years. D. S. Wilks.

EAS 341 Atmospheric Thermodynamics and Hydrostatics
Fall. 3 credits. Prerequisites: 1 year of calculus and 1 semester of physics. M. W. Wysocki.

EAS 342 Atmospheric Dynamics (also ASTRO 342)
Spring 3 credits. Prerequisites: 1 year each of calculus and physics. K. H. Cook and P. J. Gierasch.

EAS 350 Dynamics of Marine Ecosystems
Fall. 3 credits. Prerequisites: 1 year of calculus and a semester of oceanography (i.e., EAS 154), or instructor's permission. C. H. Greene.

EAS 352 Synoptic Meteorology I
Spring. 3 credits. Prerequisites: EAS 341 and concurrent enrollment in EAS 342. M. W. Wysocki.

EAS 355 Mineralogy
Fall. 4 credits. Prerequisite: EAS 101 or 201 and CHEM 207 or permission of instructor. S. Mahlburg Kay.

EAS 356 Petrology and Geochemistry
Spring. 4 credits. Prerequisite: EAS 355. R. W. Kay.

EAS 375 Sedimentology and Stratigraphy
Fall. 4 credits. Prerequisite: EAS 101 or 201. J. L. Cisne.

EAS 388 Geophysics and Geotectonics
Spring. 4 credits. Prerequisites: MATH 192 (or 112) and PHYS 208 or 213. B. L. Isacks.

EAS 417 Field Mapping in Argentina
Summer. 3 credits. Prerequisites: EAS 210 and 326; Spanish desirable but not required. S. Mahlburg Kay.

EAS 434 Reflection Seismology
Fall. 3 credits. Prerequisites: MATH 192 and PHYS 208, 213, or equivalent. L. D. Brown.

EAS 435 Statistical Methods in Meteorology and Climatology
Fall. 3 credits. Prerequisites: an introductory course in statistics (e.g., AEM 210) and calculus. D. S. Wilks.

EAS 437 Geophysical Field Methods
Fall. 3 credits. Prerequisite: PHYS 213 or 208 or permission of instructor. L. D. Brown.

EAS 447 Physical Meteorology
Fall. 3 credits. Prerequisites: 1 year each of calculus and physics. Offered alternate years. A. T. DeGaetano.

EAS 451 Synoptic Meteorology II
Fall. 3 credits. Prerequisites: EAS 341 and 342. S. J. Colucci.

EAS 453 Advanced Petrology
Fall. 3 credits. Prerequisite: EAS 356. Offered alternate years. R. W. Kay.

[EAS 454 Advanced Mineralogy
Spring. 3 credits. Prerequisite: EAS 355 or permission of instructor. Offered alternate years. Not offered 2003–2004. S. M. Kay.]

EAS 455 Geochemistry
Fall. 4 credits. Prerequisites: CHEM 207 and MATH 192 or equivalent. Recommended: EAS 356. Offered alternate years. W. M. White.

EAS 456 Mesoscale Meteorology
Spring. 3 credits. Prerequisites: EAS 341 and 342 or permission of instructor. Offered alternate years. S. J. Colucci.

[EAS 457 Atmospheric Air Pollution
Fall. 3 credits. Prerequisites: EAS 341 or 1 course in thermodynamics, and one semester of chemistry, or permission of instructor. Offered alternate years. Not offered 2003–2004. M. W. Wysocki.]

[EAS 458 Volcanology
Fall. 3 credits. Prerequisite: EAS 356 or equivalent. Offered alternate years. Not offered 2003–2004. R. W. Kay and W. M. White.]

[EAS 462 Marine Ecology (also offered as BIOEE 462)
Spring. 3 credits. Limited to 75 students. Prerequisite: BIOEE 261. Offered alternate years. Not offered 2003–2004. C. D. Harvell, C. H. Greene.]

EAS 475 Special Topics in Oceanography
Fall, spring, summer. 2–6 var. credits. Prerequisites: one semester of oceanography and permission of instructor. Fall, spring: C. H. Greene; summer: B. C. Monger.

[EAS 476 Sedimentary Basins: Tectonics and Mechanics
Fall. 3 credits. Prerequisite: EAS 375 or permission of instructor. Offered alternate years. Not offered 2003–2004. T. E. Jordan.]

EAS 478 Advanced Stratigraphy
Fall. 3 credits. Prerequisite: EAS 375 or permission of instructor. Offered alternate years. T. E. Jordan.

EAS 479 Paleobiology (also BIOEE 479)
Fall. 4 credits. Prerequisites: 1 year of introductory biology and either BIOEE 274 or 373 or EAS 375, or permission of instructor. Offered alternate years. W. Allmon.

EAS 481 Senior Survey of Earth Systems
Spring. 3 credits. Limited to seniors majoring in geological science. J. M. Bird.

[EAS 483 Environmental Biophysics
Spring. 3 credits. Prerequisite: EAS/CSS 260 or equivalent, or permission of instructor. Offered alternate years. Not offered 2003–2004. S. J. Riha.]

EAS 487 Intro to Radar and Remote Sensing (also ECE 487)
Fall. 3 credits. Prerequisites: PHYS 208 or 213 or equivalent or permission of instructor. D. L. Hysell.

EAS 491–492 Undergraduate Research
Fall, spring. 1–4 credits. Staff.

EAS 494 Special Topics in Atmospheric Science
Fall, spring. 8 credits maximum. S-U grades optional. Undergraduate level.

EAS 496 Internship Experience
Fall, spring. 1–2 credits. S-U grades only.

EAS 497 Individual Study in Atmospheric Science
Fall, spring. 1–6 credits. S-U grades optional. Students must register with an Independent Study form.

EAS 498 Teaching Experience in Earth and Atmospheric Sciences
Fall, spring. 1–4 credits. S-U grades only. Students must register with an Independent Study form.

EAS 499 Undergraduate Research in Atmospheric Science
Fall, spring. Credit by arrangement. S-U grades only. Students must register with an Independent Study form.

EAS 500 Design Project in Geohydrology
Fall, spring. 3–12 credits. An alternative to an industrial project for M.Eng. students choosing the geohydrology option. May continue over two or more semesters. L. M. Cathles.

EAS 502 Case Histories in Groundwater Analysis
Spring. 4 credits. L. M. Cathles.

[EAS 622 Advanced Structural Geology I
Spring. 3 credits. Prerequisites: EAS 326 and permission of instructor. Offered alternate years. Not offered 2003–2004. R. W. Allmendinger.]

EAS 624 Advanced Structural Geology II
Spring. 3 credits. Prerequisites: EAS 326 and permission of instructor. Offered alternate years. R. W. Allmendinger.

EAS 628 Geology of Orogenic Belts
Spring. 3 credits. Prerequisite: permission of instructor. J. M. Bird.

[EAS 634 Advanced Geophysics I: Fractals and Chaos in Geology and Geophysics
Fall. 3 credits. Prerequisite: EAS 388 or permission of instructor. Offered alternate years. Not offered 2003–2004.]

[EAS 636 Advanced Geophysics II: Quantitative Geodynamics
Spring. 3 credits. Prerequisite: EAS 388 or permission of instructor. Offered alternate years. Not offered 2003–2004.]

[EAS 641 Analysis of Biogeochemical Systems
Spring. 3 credits. Prerequisite: MATH 293 or permission of instructor. Offered alternate years. Not offered 2003–2004. L. A. Derry.]

[EAS 651 Atmospheric Physics (also ASTRO 651)
Fall. 3 credits. Prerequisites: EAS 341 and 342 or permission of instructor. Offered alternate years. Not offered 2003–2004. K. H. Cook, P. J. Gierasch, S. J. Colucci.]

[EAS 652 Advanced Atmospheric Dynamics
Spring. 3 credits. Prerequisites: EAS 341 and 342 or permission of instructor. Offered alternate years. Not offered 2003–2004. S. J. Colucci, P. J. Gierasch.]

[EAS 656 Isotope Geochemistry
Spring. 3 credits. Open to undergraduates. Prerequisite: EAS 455 or permission of instructor. Offered alternate years. Not offered 2003–2004. W. M. White.]

[EAS 666 Applied Multivariate Statistics
Spring. 3 credits. Prerequisites: multivariate calculus, matrix algebra, and two previous courses in statistics. Offered alternate years. Not offered 2003–2004. D. S. Wilks.]

EAS 675 Modeling the Soil-Plant-Atmosphere System
Spring. 3 credits. Prerequisite: EAS/CSS 483 or equivalent. Offered alternate years. S. J. Riha.

EAS 692 Special Topics in Atmospheric Science
Fall, spring. 1–6 credits. S-U grades optional. Staff.

EAS 695 Computer Methods in Geological Sciences
Fall, spring. 3 credits. L. Brown, B. L. Isacks.

EAS 700–799 Seminars and Special Work
Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.
Advanced work on original investigations in earth and atmospheric sciences. Topics change from term to term.

EAS 711 Upper Atmospheric and Space Physics
D. L. Hysell.

EAS 722 Advanced Topics in Structural Geology
R. W. Allmendinger.

EAS 731 Plate Tectonics and Geology
J. M. Bird.

EAS 751 Petrology and Geochemistry
R. W. Kay.

EAS 755 Advanced Topics in Petrology and Geochemistry
J. M. Bird.

EAS 757 Current Research in Petrology and Geochemistry
S. Mahlburg Kay, R. W. Kay.

EAS 762 Advanced Topics in Paleobiology
W. D. Allmon.

EAS 771 Advanced Topics in Sedimentology and Stratigraphy
T. E. Jordan.

EAS 773 Paleobiology
J. L. Cisne.

EAS 775 Advanced Topics in Oceanography
Spring. C. H. Greene.

EAS 780 Earthquake Record Reading
Fall. M. Barazangi.

EAS 781 Geophysics, Exploration Seismology, Ground-Penetrating Radar
L. D. Brown.

EAS 783 Advanced Topics in Geophysics
B. L. Isacks.

EAS 789 Lithospheric Seismology
L. D. Brown.

EAS 793 Andes-Himalaya Seminar
S. Mahlburg Kay, R. W. Allmendinger, B. L. Isacks, T. E. Jordan.

EAS 795 Low Temperature Geochemistry
L. A. Derry.

EAS 796 Geochemistry of the Solid Earth
W. M. White.

EAS 797 Fluid-Rock Interactions
L. M. Cathles.

EAS 799 Soil, Water, and Geology Seminar
L. M. Cathles, T. S. Steenhuis.

EAS 850 Master's-Level Thesis Research in Atmospheric Science
Fall, spring. Credit by arrangement. S-U grades only. Hours by arrangement. Graduate faculty.

EAS 950 Graduate-Level Dissertation Research in Atmospheric Science
Fall, spring. Credit by arrangement. S-U grades optional. Hours by arrangement. Graduate faculty.

EAS 951 Doctoral-Level Dissertation Research in Atmospheric Science
Fall, spring. Credit by arrangement. S-U grades optional. Hours by arrangement. Graduate faculty.

ELECTRICAL AND COMPUTER ENGINEERING

ECE 210 Introduction to Circuits for Electrical and Computer Engineers (also ENGRD 210)
Fall, spring. 3 or 4 credits. Corequisites: MATH 293 and PHYS 213. ECE majors must take 4 credits, includes a design project. Non-ECE majors can take 3 credits. All students must take the lab. Fall, J. C. Belina, C. E. Seyler; spring, M. C. Kelley.
For description, see ENGRD 210.

ECE 250 Technology in Society (also ENGRG 250, HIST 250 and S&TS 250)
Fall. 3 credits. A humanities elective for engineering students. R. R. Kline.
For description, see ENGRG 250.

ECE 291–292 Sophomore Electrical and Computer Engineering Project
Fall, 291; spring, 292. 1–8 credits. Limited to sophomores in Engineering. Staff.
Individual study, analysis, and, usually, experimental tests 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 prior to registration and submit a request for Independent Project form to the Electrical and Computer Engineering Undergraduate Office.

ECE 298 Inventing an Information Society (also ENGRG 298 and S&TS 292)
Spring. 3 credits. Approved for humanities distribution. R. R. Kline.
For description, see ENGRG 298.

ECE 301 Signals and Systems I
Fall. 4 credits. Prerequisites: a grade of at least C+ in ENGRD 210, and C in MATH 293 and 294. D. F. Delchamps, H. Chiang.
Covers: continuous-time signals and linear time-invariant systems, continuous-time convolution and impulse response, Fourier series and transforms of continuous-time signals, the Sampling Theorem, amplitude modulation and time- and frequency-division multiplexing, bilateral Laplace transforms and applications, and discrete-time convolution and z-transforms with applications to discrete-time linear time-invariant systems.

ECE 302 Introduction to Digital Signal Processing
Spring. 4 credits. Prerequisite: ECE 301. S. S. Hemami.
Topics include: discrete time signals and LTI systems; Z-transform and discrete-time Fourier transform; ideal and practical sampling and interpolation; the discrete Fourier transform (DFT); practical DSP applications of the DFT; and the fast Fourier transform.

ECE 303 Electromagnetic Fields and Waves
Fall. 4 credits. Prerequisites: grades of C or better in PHYS 213, 214, and MATH 294. D. T. Farley, J. R. Shealy.
Maxwell's equations in differential form; wave equation; plane electromagnetic waves; phase and group velocities; Poynting's theorem, complex dielectric constant; wave reflection and transmission; guided waves on transmission lines; transient pulse propagation;

and elementary dipole antenna; analysis of wireless communication links.

ECE 306 Fundamentals of Quantum and Solid-State Electronics

Spring. 4 credits. Prerequisites: PHYS 214 and MATH 294. C. L. Tang.

Introductory quantum mechanics and solid-state physics necessary for modern solid-state electronic devices. Topics include the formalism and methods of quantum mechanics, the hydrogen atom, the structure of simple solids, energy bands, Fermi-Dirac statistics, and the basic physics of semiconductors. Applications include quantum wells and the p-n junction.

ECE 310 Introduction to Probability and Random Signals

Spring. 4 credits. Prerequisite: MATH 294. This course may be used in place of ENGRD 270 to help satisfy the engineering distribution requirement. T. L. Fine.

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, and device modeling, probability, and characteristic functions; nonlinear transformations of data; expectation and correlation; and the central limit theorem.

ECE 311 Electrical and Computer Engineering Honors Seminar

Spring. 1 or 2 credits. Staff.

Students registered for this course are required to attend all of the colloquia lectures. Summary papers are required. Honors students who take the seminar for letter grade are required to write two summary papers for two credits. Non-honors students, who must take the seminar pass/fail, are required to write one summary paper for one credit. Each summary paper reviews a topic presented during the term.

ECE 314 Computer Organization (also COM S 314)

Fall, spring. 4 credits. Prerequisites: COM S/ENGRD 211 or ENGRD 230 required. Fall; COM S staff; spring, S. A. McKee.

Course description for spring offering: basic computer organization. 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. For fall description, see COM S 314.

ECE 315 Introduction to Microelectronics

Fall, spring. 4 credits. Prerequisites: ECE 210 and ECE 215. Fall, A. Lal, A. Apsel; spring, B. A. Minch.

Design of digital and analog electronic circuits in the context of modern integrated circuit technology. Course coverage includes the building blocks of integrated circuits: introductory physics of semiconductors, MOS and junction transistors; digital electronics—inverters, logic circuits, and memory; and analog circuits—multi-stage and differential amplifiers.

ECE 336 Nanofabrication

Spring. 3 credits. Prerequisites: PHYS 213 or 217, PHYS 214 or 218; CHEM 211 or 207; or equivalent. E. C. Kan.

Fundamentals of nanofabrication for integrated circuits, optoelectronics, micro-electro mechanical systems (MEMS), sensors, (nano)biotechnology, biology, chemistry, and micro-systems. Hands-on and virtual laboratory as facilitated by available resources. Designed for electrical/computer engineering, materials science/engineering, mechanical/aerospace engineering, chemical engineering, applied/engineering physics, agricultural/biological engineering, biology, and chemistry students.

ECE 391–392 Junior Electrical and Computer Engineering Project

Fall, 391; spring, 392. 1–8 credits. Limited to juniors in Engineering.

Individual study, analysis, and, usually, experimental tests 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 prior to registration and submit a Request for Independent Project form to the Electrical Engineering Undergraduate Office.

ECE 402 Biomedical System Design (also BMEP 404)

Spring. 1–4 credits. Co- or prerequisites: at least one of: ECE 425, ECE 476, ECE 453. J. C. Belina.

Course 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 6 or 7 weeks devoted to designing/prototyping a safe and effective "ambulatory microprocessor-controlled blood pressuremonitor." Formal design document is required. ECE 402 is a culminating design experience (CDE) course.

ECE 411 Random Signals in Communications and Signal Processing

Fall. 3 credits. Prerequisite: ECE 301 and 310 or equivalent. A. Scaglione.

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 413 Introduction to Nuclear Science and Engineering (also M&AE 458)

Fall. 3 credits. Prerequisites: PHYS 214 and MATH 294. K. B. Cady.

This course is designed for juniors or seniors from any engineering field who want to prepare for graduate-level nuclear science and engineering courses at Cornell or elsewhere. It can also serve as a basic course for those who do not intend to continue in the field. Introduction to the fundamentals of nuclear reactors. Topics include an overview of the field of nuclear engineering; nuclear structure, radioactivity, and reactions; interaction of radiation and matter; and neutron moderation, neutron diffusion, the steady-state chain reaction, and reactor kinetics.

ECE 415 GPS: Theory and Design (also M&AE 415)

Fall. 4 credits. Prerequisite: a 300-level engineering course with advanced math content such as ECE 301 or ECE 303, or MAE 326. P. M. Kintner.

An 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 415 is a culminating design experience (CDE) course.

ECE 425 Digital Signal Processing

Fall. 4 credits. Prerequisites: ECE 301, ECE 302, and ECE 310. T. W. Parks, B. A. Hutchins.

An advanced course in digital signal processing. Topics include sampling, A/D and D/A conversion, digital filter design and implementation, multirate DSP including sampling rate conversion and filter bank theory, Wiener filtering, spectral estimation, introduction to two-dimensional sampling, and Fourier techniques.

ECE 426 Applications of Signal Processing

Spring. 4 credits. Prerequisite: ECE 425. B. A. Hutchins.

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 426 is a culminating design experience (CDE) course.

ECE 430 Lasers and Optical Electronics

Fall. 4 credits. Prerequisite: ECE 303 or equivalent. C. L. Tang.

An introduction to the operation and application of lasers. Material covered includes diffraction-limited optics, Gaussian beams, optical resonators, interaction of radiation with matter, physics of laser operation, and laser design. Applications of coherent radiation to nonlinear optics, communication, and research are discussed.

ECE 432 MicroElectro Mechanical Systems (MEMS)

Spring. 3 credits. Prerequisite: ECE 315 or permission of instructor. A. Lal.

Introductory course 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 432 is a culminating design experience (CDE) course.

ECE 433 Introduction to Microwave Devices and Circuits

Fall. 4 credits. Prerequisites: ECE 303 and ECE 306. Staff.

An introduction to the properties of microwave devices and circuits and the considerations that must be appreciated when the operating frequency approaches or exceeds 1 GHz. 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. Laboratories cover basic measurement techniques for active and passive elements as well as low noise amplifier design.

ECE 437 Fiber and Integrated Optics
Spring. 4 credits with a project. Prerequisite: ECE 303 or equivalent. M. Lipson.
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 437 is a culminating design experience (CDE) course.

ECE 445 Computer Networks and Telecommunications
Fall. 4 credits. Prerequisites: ECE 314 (or COM S 314) and a course in probability. S. Servetto.
Design of performance analysis of communication systems operating over packet-switched networks. This is a basic course in networking that aims to bridge the gap between a classical networking class and a classical digital communications class. The course is lab oriented, with a strong emphasis on programming assignments (both C and Matlab). Topics covered include data compression, error control in networks, and network algorithms. ECE 445 is a culminating design experience (CDE) course.

ECE 451 Electric Power Systems I
Fall. 3 credits. Prerequisite: ECE 301 or equivalent. J. S. Thorp.
The objective is to acquaint the student with modern electric power system analysis and control. Analysis techniques appropriate for the restructured industry and advanced protection and control systems are stressed. 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 452 Electric Power Systems II
Spring. 3 credits. Prerequisite: ECE 451 or permission of instructor. R. J. Thomas.
Acquaints students with modern electric power system operation and control. Aspects of the restructuring of the industry and its implications for planning and operation objectives and methods are explored. 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 453 Analog Integrated Circuit Design
Fall. 4 credits. Prerequisites: ECE 301 and ECE 315 or equivalent. ECE 457 recommended as a corequisite. B. A. Minch.
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 453 is a culminating design experience (CDE) course.

ECE 457 Silicon Device Fundamentals
Fall. 4 credits. Prerequisites: ECE 315 and ECE 306 or MSE 262 or AEP 450. E. C. Kan.
Semiconductor carrier statistics, band diagrams, transport and their applications in diodes, MOSFET, and BJT. Emphasis is put on the CMOS operations for advanced VLSI technology. Six labs cover device measurements and design by simulation. By using the combined simulation and measurement, the course culminates in a comprehensive design project dealing with technical concerns in current VLSI industry as well as its economical, environmental, and social impacts. ECE 457 is a culminating design experience (CDE) course.

ECE 467 Telecommunication Systems I
Fall. 4 credits. Prerequisites: ECE 301 and ECE 302. C. R. Johnson.
An 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 467 is a culminating design experience (CDE) course.

ECE 468 Telecommunication Systems II
Spring. 4 credits. Prerequisite: ECE 467 or permission of instructor. Suggested prerequisite: ECE 411. C. R. Johnson.
Fundamentals of digital communications. Topics include: digital source coding, Huffman coding, sampling, quantization, analog source coding; optimum receivers for digital transmission through additive white Gaussian noise (AWGN) channels, matched filters; channel capacity and error control coding; digital transmission through bandlimited AWGN channels, inter-symbol interference (ISI), equalization techniques; phase-locked loops (PLL); trellis-coded modulation (TCM); and spread-spectrum communication systems.

ECE 472 Feedback Control Systems (also CHEME 472 and M&AE 478)
Spring. 4 credits. Prerequisite: CHEME 372, ECE 301, M&AE 326, or permission of instructor. Staff.
For description, see M&AE 478.

ECE 474 Digital VLSI Design
Fall and spring. 5 credits (fall 4, spring 1). Prerequisites: ENGRD 230, ECE/CS 314. Students will receive an R grade until they test their chips in the spring. R. Manohar.
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. Students tape out a small project that is tested in the following semester. The course also includes an introduction to asynchronous design. ECE 474 is a culminating design experience (CDE) course.

ECE 475 Computer Architecture
Fall. 4 credits. Prerequisites: ENGRD 230 and ECE or COM S 314. J. F. Martínez.
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 tradeoffs involved in the design of modern microprocessors. Labs involve the design of a processor and cache subsystem at the RTL level. ECE 475 is a culminating design experience (CDE) course.

ECE 476 Digital Systems Design Using Microcontrollers
Spring. 4 credits. Prerequisite: ECE/COM S 314 (ECE 315 strongly recommended). B. R. Land.
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 476 is a culminating design experience (CDE) course.

ECE 484 Introduction to Controlled Fusion: Principles and Technology (also M&AE 459 and NS&E 484)
Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics. Intended for seniors and graduate students in engineering and the physical sciences. Offered alternate years. D. A. Hammer.
For description, see NS&E 484.

ECE 486 Electromagnetic Waves and Communication
Spring. 3 credits. Prerequisite: ECE 303. D. L. Hysell.
This course is recommended for students who wish to obtain a greater understanding of the fundamentals of guided waves, high data rate electronics and wireless communication. Topics covered include vector and scalar potentials, transmission lines, waveguides, fiber optics, antenna arrays, and propagation in different environments including interference and diffraction.

ECE 487 Introduction to Radar and Remote Sensing
Fall. 3 credits. Prerequisites: ECE 301 and ECE 486 (or a grade of B or better in ECE 303). D. L. Hysell.
Fundamentals of antenna theory, including gain and effective area, near and far fields, phased arrays, and aperture antennas and aperture synthesis. Fundamentals of radar, including detection, tracking, Doppler shifts, sampling, and range and frequency aliasing. Synthetic aperture radars and remote sensing from aircraft and satellites; over-the-horizon (OTH) radars and ionospheric propagation effects; and radar astronomy techniques.

ECE 488 RF Circuits and Systems
Spring. 4 credits. Prerequisites: ECE 315 or equivalent. 2 design credits. Lab credit. W. E. Schwartz.
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. Five laboratory sessions. ECE 488 is a culminating design experience (CDE) course.

ECE 491–492 Senior Electrical and Computer Engineering Project
Fall, 491; spring, 492. 1–8 credits. Limited to seniors in Engineering.
Individual study, analysis, and, usually, experimental tests 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 prior to registration for this course and submit a request for an independent project form to the Electrical Engineering undergraduate office.

ECE 495 Optimizing Compilers
Fall. 4 credits. Prerequisite: ECE/COM S 314. M. Burtscher.
This course provides in-depth coverage of modern compiler optimizations for high-performance microprocessors. Topics include static single assignment form (SSA), redundancy elimination, loop optimizations, procedure optimizations, register allocation, instruction scheduling, control-flow optimizations, interprocedural analysis and optimization, numerous "small" optimizations, and feedback optimizations. The projects involve implementing, testing, and evaluating a number of advanced compiler optimizations for a high-end microprocessor.

ECE 496 Principles of Large Scale, Complex Adaptive Networks
Spring. 4 credits. Prerequisites: ECE requirements through the 200 level, plus some knowledge of probability. Recommended for junior and senior ECE students interested in the systems area. S. Ben-David.
Large-scale complex adaptive (LSCA) networks in ECE include the Internet; World Wide Web; bulk electric power distribution systems; wireless and wired telecommunications networks. We study several principles common to LSCA networks. Each principle will be introduced in the context of a particular large-scale complex adaptive network, abstracted to expose its mathematical essentials, and then illustrated and developed through calculations and/or simulations.

ECE 512 Applied Systems Engineering I (also CEE 504, COM S 504, M&AE 591, OR&IE 512, SYSEN 510)
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. M. Campbell, R. O. Roundy.
For description, see M&AE 591.

ECE 513 Applied Systems Engineering II (also CEE 505, COM S 505, M&AE 592, OR&IE 513, SYSEN 520)
Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 591, or OR&IE 512). R. Thomas, L. Nozick, P. Jackson.
For description, see M&AE 592.

ECE 521 Theory of Linear Systems
Fall. 4 credits. Prerequisite: ECE 302 or permission of instructor. Recommended: a good background in linear algebra and linear differential equations. A. W. Bojanczyk.
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 T. Kailath.

[ECE 525 Adaptive Filtering in Communication Systems
Spring. 4 credits. Required prerequisite: ECE 411 and ECE 467. Not offered 2003–2004. C. R. Jackson.
Fundamentals of theory for adaptive filters intended for digital communication systems applications. Wired and wireless communication systems tasks (such as channel equalization, echo cancellation, antenna beam forming, and interference rejection) are used to motivate adaptive filter design issues. Assignments consist of reports on adaptive digital filter algorithms and their simulated evaluation.]

ECE 526 Signal Representation and Modelling
Spring. 4 credits. Prerequisites: ECE 425. T. W. Parks.
Sampling and signal reconstruction. Approximation theory. Linear inversion theory. Exponential signal modelling. Multirate filter banks, wavelets, and lifting. Laboratory experiments with speech and image signals.

ECE 531 Applied Quantum Optics for Photonics and Optoelectronics
Fall. 4 credits. Prerequisites: ECE 306 and 407, or PHYS 443. F. Rana.
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 535 Semiconductor Physics
Fall. 4 credits. Prerequisites: ECE 407 and 457, or permission of instructor. S. Tiwari.
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. On the level of *Compound Semiconductor Device Physics* by S. Tiwari.

ECE 547 Computer Vision
Fall. 4 credits. Prerequisites: ECE 302 (or COM S 280 and 314) or consent of instructor. A. P. Reeves.
Computer acquisition and analysis of image data with emphasis on techniques for robot vision. This course 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 548 Digital Image Processing
Fall. 4 credits. Prerequisites: ECE 411, ECE 425, familiarity with linear algebra. S. S. Hemami.
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 551 Electric Systems Engineering and Economics (Electricity Markets) (also AEM 655)
Fall. 2 credits. Prerequisites: basic calculus, microeconomics. R. J. Thomas, T. D. Mount.
This course is designed to explore new arrangements in power system planning and operation brought about by the current restructuring of the electric industry. The course is organized around lectures on 1) how basic economic principles interact with basic engineering principles used to determine the physical and operational makeup of the system; and 2) the principles and techniques of optimization and their applications to emerging institutional arrangements in the power industry. The course involves extensive laboratory work designed to test the principles under discussion. A final project is assigned, requiring building an intelligent software agent capable of performing in a competitive market with rules similar to those being set up in the electric power business today. The agents are exercised in a class competition.

ECE 554 Advanced Analog VLSI Circuit Design
Spring. 4 credits. Prerequisite: ECE 453. A. B. Apsel.
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 558 Compound Semiconductor Electronics
Spring. 3 or 4 credits; 4 with a project. Prerequisite: ECE 457 or equivalent. Not offered 2003–2004.
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 561 Error Control Codes
Fall. 4 credits. Prerequisite: ECE 301 or ECE 521 or equivalent. A strong familiarity with linear algebra is assumed.
S. B. Wicker.
An introduction to the theory and practice of error control codes. Topics include algebraic codes, convolutional codes, concatenated codes, and codes on graphs. The construction and decoding of Reed-Solomon (RS) codes will be considered in some detail, as will the iterative (turbo) decoding of concatenated codes and codes on graphs. The use of error control in wireless systems will be discussed throughout the course.

ECE 562 Fundamental Information Theory
Spring. 4 credits. Prerequisite: ECE 310 or equivalent. Staff.
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 563 Communication Networks
Fall. 4 credits. Prerequisite: ECE 411 or permission of instructor. Z. Haas.
Classical line-switched communication networks: point-process models for offered traffic; blocking and queuing analyses. Stability, throughput, and delay of distributed algorithms for packet-switched transmission of data over local-area and wide-area nets. Flow control and capacity assignment algorithms, ATM networks.

ECE 564 Detection and Estimation
Spring. 4 credits. Prerequisites: ECE 310, ECE 411, or instructor's consent. L. Tong.
A 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 566 Wireless Networks
Spring. 4 credits. Prerequisites: ECE 445 and ECE 411. Not offered 2003–2004.
Z. Haas.
An introductory course in mobile and wireless networks. The course is targeted mainly at the graduate level but is open to undergraduates as well. The course covers fundamental techniques and protocols in the design and operation of the first, second, and third generation of wireless networks. Examples of related topics include cellular systems, medium access control, control of a mobile session and a mobile call, signaling in mobile networks, mobility management techniques, common air interfaces (AMPS, IS-136, IS-95, GSM), wireless data (CDPD, Mobitex), satellite communication, ad hoc networks (Bluetooth), Internet Mobility, Personal Communication Services (PCS), and so on.]

ECE 567 Digital Communications
Fall. 4 credits. Prerequisites: ECE 310, ECE 411, or instructor's consent. L. Tong.
A graduate-level introduction to fundamentals of digital communications. Complex random signals. Digital modulations and optimal receiver principles. Baseband and passband transmissions and processing. Interference channels and equalization techniques. Performance analysis including bit error rate calculation and bounds, cutoff rate and channel capacity. Applications in wireless and digital subscriber loops (DSL).

ECE 568 Mobile Communication Systems
Spring. 4 credits. Prerequisites: ECE 411 and ECE 467; corequisite: ECE 468.
A. Scaglione.
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 572 Parallel Computer Architecture
Spring. 4 credits. Prerequisite/corequisite: ECE 475. J. F. Martínez..
Principles and tradeoffs 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 574 Advanced Digital VLSI Design
Spring. 4 credits. Prerequisites: ECE 474, ECE 475. R. Manohar.
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 complete a group project of the design of a pipelined microprocessor. The processor can be clocked, asynchronous, or a combination of the two. Note: the only difference between taking and not taking ECE 576 is fabricating and testing the chip. All students have to design one.

ECE 575 High-Performance Processor Architecture
Spring. 3 credits. Prerequisite: ECE 475.
M. Burtscher.
This course provides in-depth coverage of the advanced architectural features of current and next-generation high-performance microprocessors. Topics include superscalar design, out-of-order execution, register renaming, caching, value prediction, confidence estimation, branch prediction, predication, control speculation, multithreading, compiler optimizations, and case studies of existing processors. Projects involve writing simulators to evaluate the performance of various microprocessor components.

ECE 576 Advanced Digital VLSI Design Project
Course starts in spring term and finishes the following fall (2-semester course). 5 credits. Prerequisites: ECE 474, ECE 475. Groups receive an R in ECE 576, for the spring, until they fabricate and test their chips the following fall. Offered spring 2004 and fall 2004. R. Manohar.
For description, see ECE 574.

[ECE 577 Feedforward Neural Networks
Fall. 4 credits. Prerequisite: ECE 310. Not offered 2003–2004. T. L. Fine.
Feedforward neural networks (multilayer perceptrons) are computing systems formed out of many highly interconnected nonlinear memoryless elements that are arranged in a parallel architecture that is loosely modeled on that of the brain. Focus is on their roles as pattern classifiers, signal processors, estimators, and forecasters and on their role in communication systems. Includes exploration of neural networks through mathematical analyses and extensive simulation studies using MATLAB.]

ECE 579 Radio Frequency (RF) Integrated Circuit Design
Fall and spring. 6 credits. Prerequisites: ECE 433, ECE 453, and ECE 488.
K. T. Kornegay.
This two semester, 6-credit, course conveys practical knowledge of advanced concepts related to the design radio-frequency (RF) integrated circuits in state-of-the-art silicon germanium (SiGe) technology. Emphasis is on the circuit architecture, design, trade-offs, optimization, and layout of RF integrated circuits for use in wireless applications. Special attention is devoted to the most important challenges facing RF circuit designers today, such as the impact of noise, power distribution, and consumption. Low noise amplifier, voltage-controlled oscillator (VCO), phase-lock loop, and high-performance mixer design are emphasized. The basic transmitter/receiver building blocks are covered, and students learn how to design and assemble them to form single-chip wireless systems.

ECE 581 Introduction to Plasma Physics
Fall. 4 credits. Prerequisite: ECE 303 or equivalent. First-year graduate-level course; open to exceptional seniors.
D. A. Hammer.
Topics covered 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 585 Upper Atmospheric Physics I
Fall. 4 credits. Prerequisites: Physics through 214 or equivalent, introductory chemistry, ECE 486 or equivalent.
M. C. Kelley.
The structure and dynamics of the ionosphere and upper atmosphere. Charged particle production, loss, and transport. Coupling to the neutral atmosphere. Ionospheric instabilities. High-latitude currents and plasma convection and its implications for the ionosphere and upper atmosphere.

ECE 586 Upper Atmospheric Physics II
Spring. 4 credits. Prerequisites: ECE 581 and ECE 585. C. E. Seyler.
Topics include solar phenomena, solar wind, and space weather; magnetospheric structure and physical processes; plasma instabilities in the ionosphere and magnetosphere; and magnetic reconnection and the relation to high-latitude phenomena.

ECE 587 Energy Seminar (also NS&E 545 and M&AE 545)
Fall, spring. 1 credit. May be taken for credit both semesters. E. Fisher.
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. Examples of topics to be surveyed include: energy resources and economics; coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; and air pollution control.

ECE 596 VLSI for Optical Interconnects
Spring. 4 credits. Prerequisites: ECE 315, ECE 453, or permission of instructor. A. B. Apsel.
This course is a graduate-level introduction to the concepts of optoelectronic interconnects. We will cover high-speed circuit design of transmitters and receivers for chip-to-chip and Ethernet communication channels. Topics include transimpedance amplifiers, data formats, introduction to optical devices, drivers, comparisons to conventional interconnect, and novel receiver architectures.

ECE 598 Contemporary Topics in Micromachined Microsystems
Spring. 3 credits. A. Lal.
Contemporary topics in MEMS will be covered with a focus on using science and engineering to analyze the why and how of MEMS/NEMS solutions. The aim of this course is to learn how to think about the microsystems. The focus areas will be communication systems incorporating MEMS and autonomous systems incorporating MEMS.

ECE 630 Photonics
Fall. 3 credits. M. Lipson.
This course covers the primary advances in the photonic field with emphasis on emerging technologies. Typical topics include novel optical materials, optical MEMS, Photonic Band Gaps and the role of optics in next-generation computers.

ECE 672 Distributed Systems
Fall. 3 credits. Prerequisite: ECE 475. W. E. Speight.
Design of distributed systems, with particular emphasis on the field of cluster-based architectures. Students read papers, discuss topics in class, make presentations to the class, and complete a major software design project. Topics include runtime system design, coherence protocols for software distributed shared memory systems, fault-tolerant systems, file access, emerging interconnection networks, process and thread migration, adaptive systems, and cluster-based solutions for web servers and multimedia applications.

[ECE 682 Advanced Plasma Physics
Spring. 3 credits. Prerequisite: ECE 581. Not offered 2003–2004. C. E. Seyler.
Boltzmann and Vlasov Equations; dielectric tensor; waves in hot magnetized plasmas; Landau and cyclotron damping; microinstabilities; low-frequency stability; nonlinear phenomena; solitons and nonlinear wave equations; ponderomotive effects and parametric processes; plasma models.]

ECE 691–692 Electrical and Computer Engineering Colloquium
Fall, 691; spring, 692. 1 credit each term. For students enrolled in the graduate field of Electrical and Computer Engineering. Staff.
Lectures by staff, graduate students, and visiting authorities. A weekly meeting for the presentation and discussion of important current topics in the field. Reports required.

ECE 693–694 Master of Engineering Design
Fall, 693; spring, 694. 1–8 credits. For students enrolled in the M.Eng. (Electrical) 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 696 Topics in Communications
Spring. 3 credits. Prerequisite: ECE 562. Not offered 2003–2004.
Introduction to multi-user problems in information theory (such as multiple access and broadcast channels, distributed correlated sources, coding with side information, multiple descriptions), and to classical networking problems (such as routing, flow control, delay, performance of protocols). Emphasis is on developing tools needed to do research work in this area.]

ECE 697 Topics in Computer Systems
Fall, spring. 1 credit. S-U only. Prerequisites: ECE 475 and interest in computer systems. S. A. McKee, staff.
A course for systems graduate students in which the class reads papers about the design and implementation of computer systems and their components. Influential papers from the past as well as papers describing current research and development efforts are discussed.

ECE 791–792 Thesis Research
Fall, 791; spring, 792. 1–15 credits. For students enrolled in the master's or doctoral program.

MATERIALS SCIENCE AND ENGINEERING

Undergraduate Courses

MS&E 111 Nanotechnology (also ENGRI 111)
Fall. 3 credits. E. Giannelis.
This is a course in the Introduction to Engineering series. For description, see ENGRI 111.

MS&E 118 Design Integration: A Portable CD Player (also ENGRI 118 and T&AM 118)
Spring. 3 credits. W. Sachse.
This is a course in the Introduction to Engineering series. For description, see ENGRI 118.

MS&E 119 Biomaterials for the Skeletal Systems (also ENGRI 119)
Fall. 3 credits. D. T. Grubb.
This is a course in the Introduction to Engineering series. For description, see ENGRI 119.

MS&E 124 Designing Materials for the Computer
Spring. 3 credits. 3 lectures.
This is a course in the Introduction to Engineering series. For description, see ENGRI 124.

MS&E 204 Materials Chemistry
Spring. 4 credits.
This course is designed to give a molecular understanding of materials properties with emphasis on general concepts. In the first part, the structure of atoms is discussed introducing fundamental concepts of quantum chemistry. In the second part the transition from atoms to molecules is made discussing symmetry aspects of chemical bonding. The last part describes the transition from molecules to materials. Materials classes covered include modern examples of polymers, organic semiconductors, ceramics, organic-inorganic hybrids, and superconductors emphasizing the interdisciplinary nature of materials science. Examples illustrate current materials research involving nano-biotechnology, organic optoelectronics, self-assembling materials, or nano-ceramic.

MS&E 206 Atomic and Molecular Structure of Matter
Spring. 4 credits.
Bonding in materials; crystal structures and symmetry; defects. Crystal planes and directions; stereographic projections. Techniques for structural analysis: direct and diffraction methods. X-ray and electron diffraction. Electron microscopy.

MS&E 261 Mechanical Properties of Materials: From Nanodevices to Superstructures (also ENGRD 261)
Fall. 3 credits. S. P. Baker.
For description, see ENGRD 261.

MS&E 262 Electronic Materials for the Information Age (also ENGRD 262)
Fall. 3 credits. Prerequisite: MATH 192; Corequisite: PHYS 213 or permission of instructor. G. Malliaras.
For description, see ENGRD 262.

MS&E 265 Biological Materials and Their Synthetic Replacements
Spring. 3 credits.
From contact lenses and false teeth to arterial implants and hip joints, a tremendous range of synthetic materials are used in contact with the body to replace or supplement natural biological materials. The course considers a number of biological systems and describes the properties and structure of the natural materials. Requirements for candidate replacement materials are discussed, with historical and current solutions. These involve material properties such as strength and corrosion resistance as well as toxicity and bio-compatibility. Design constraints, including methods of production, economics, regulatory approval, and legal liabilities, are also considered.

MS&E 281 The Substance of Civilization—Materials through the Ages
Fall. 3 credits. 2 lectures, 1 lab. S. L. Sass.

Materials have enabled revolutionary advances in how we live, work, fight, travel, and play: hence the naming of eras after them—Stone, Bronze, and Iron Ages. This course explores the role of materials in the development of the modern industrial Western civilization by putting technology into an historical and human context and examining the advances made possible by innovations with materials, starting with the Stone Age. Interconnections between crucial innovations and historical events are identified and explored. Lectures, demonstrations, and hands-on laboratory experiments elucidate the origin of the unique properties of materials such as polymers, ceramics, metals, and glass. This course is designed to fulfill the science requirement in the College of Arts and Sciences.

MS&E 291–292 Research Involvement IIa and IIb

291, fall; 292, spring. 3 credits each term. 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-term affiliation with a research group.

MS&E 302 Mechanical Properties of Materials, Processing, and Design (also MS&E 582)

Spring. 4 credits. Prerequisite: MS&E 206. Corequisite: MS&E 304 or permission of instructor. Staff.

Stress and infinitesimal strain as second-rank Cartesian tensors. Linear elasticity and fourth-rank Cartesian tensors. Symmetry effects (Nye, *Physical Properties of Crystals*). Design criteria for beams, shafts, and pressure vessels (Dowling, *Mechanical Behavior of Materials*). Generalized plastic flow relations. Design based on yielding, fracture toughness, fatigue, creep, and rupture with specific applications. Basis for improved materials.

MS&E 303 Thermodynamics of Condensed Systems

Fall. 4 credits. Prerequisites: PHYS 214 and MATH 294. M. O. Thompson.

The three laws of thermodynamics are introduced as the fundamental basis for thermal and chemical equilibrium, coupled with statistical mechanical interpretations for entropy and specific heat capacities.. These principles are applied to understanding phase equilibria and phase diagrams, heterogeneous reactions, solutions, surfaces, and defects. Introduction to electrochemistry and fuel/power cells.

MS&E 304 Kinetics, Diffusion, and Phase Transformation (also MS&E 584)

Spring. 4 credits. Prerequisite: MS&E 303 or permission of instructor.

The topics covered 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 305 Electronic, Magnetic and Dielectric Properties of Materials (also MS&E 585)

Fall. 4 credits. Prerequisite: MS&E 206 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 will be emphasized.

MS&E 307 Materials Design Concept I

Fall. 2 credits. S. Sass.

For description, see MS&E 407.

MS&E 311 Junior Laboratory I

Fall. 1 credit. C. K. Ober.

Practical laboratory covering the analysis and characterization of materials and processing. The fall semester labs will be based on materials from courses in thermodynamics of condensed systems and electronic, magnetic, and dielectric properties of materials.

MS&E 312 Junior Laboratory II

Spring. 1 credit. C. K. Ober.

Practical laboratory covering the analysis and characterization of materials and processing. The spring semester labs will be based on course material in kinetics, diffusion, and phase transformation and mechanical properties of materials, processing, and design.

MS&E 391–392 Research Involvement IIIa and IIIb

391, fall; 392, spring. 3 credits each term. Prerequisite: approval of department. Staff.

For description, see MS&E 291. May be continuation or a 1-term affiliation with a research group.

MS&E 403–404 Senior Materials Laboratory I and II

403, fall, 3 credits; 404, spring, 2 credits. D. Grubb.

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.

MS&E 405–406 Senior Thesis I and II

405, fall; 406 spring. 4 credits each term. A. Ruoff.

Open to advanced undergraduates in lieu of the senior materials laboratory. Proposals for thesis topics should be approved by the supervising faculty member prior to 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. Both semesters must be taken to complete the laboratory requirement. This course is required for graduation with honors.

MS&E 407 Materials Design Concepts II

Fall. 2 credits. S. Sass.

The goal of this course is to introduce 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 will be studied in light of economic, environmental, regulatory, and safety issues. Patent searching and communication skills will be addressed. In the second portion of the course, speakers from industry lecture on case studies of materials design problems. Students give oral presentations and write technical reports based on the case studies.

MS&E 491–492 Research Involvement IVa and IVb

491 fall; 492, spring. 3 credits each term. Prerequisite: approval of department. Staff.

For description, see MS&E 291. May be continuation or a one-term affiliation with a research group.

MS&E 495 Undergraduate Teaching Involvement

Fall, spring. Variable credit. Staff.

This course will give credit to students who help in the laboratory portions of ENGRI 111, 119, or 124, ENGRD 261, or MS&E 281. The number of credits earned will be determined by the teaching load and will typically be 1–3 credits.

MS&E 512 Mechanical Properties of Thin Films

Spring. 3 credits. Offered alternate years.

Mechanical properties that are unique to materials in the form of thin films (typical thickness 1 micrometer and less) and micrometer-scale structures. Mechanics of two-dimensional structures. Stress and mechanical property measurement methods in small dimensions. Microstructural development in thin films. Elastic, plastic, and fracture response of films and constrained volumes.

MS&E 521 Properties of Solid Polymers

Fall. 3 credits. Prerequisite: ENGRD 261. Corequisite: MS&E 303 or permission of instructor. U. Wiesner.

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.

MS&E 523 Physics of Soft Materials

Fall. 3 credits. Offered alternate years. U. B. 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.

MS&E 524 Materials Chemistry of Synthetic Polymeric Materials
Fall. 3 credits. Prerequisite: MS&E 521 or permission of instructor. Offered alternate years. C. K. Ober.
Preparation of synthetic polymers by step- and chain-growth polymerization: condensation; free radical, anionic, and cationic mechanisms; ring opening and coordination routes. Statistical and kinetic aspects of homopolymer and copolymer formation. Stereochemistry of polymers and spectroscopic methods for polymer analysis. Molecular aspects of polymer design for properties such as conductivity, elasticity, thermal stability, and engineering properties. Special topics include liquid crystalline polymers, photoresists, and supermolecular chemistry. At the level of *Principles of Polymerization* by Odian.

MS&E 525 Organic Optoelectronics
Fall. 3 credits. Offered alternate years. G. G. Malliaras.
Overview of relevant materials from small aromatic molecules to conjugated polymers. Focuses on optoelectronic properties, including photophysics (absorption, emission, photogeneration, recombination), charge transport (doping, hopping, disorder, charge injection), and elements of nonlinear optics. Optoelectronics applications (such as electrophotography, light-emitting diodes, lasers, photovoltaic cells, thin film transistors) are also discussed.

MS&E 531 Introduction to Ceramics
Fall. 3 credits. R. Dieckmann.
This course 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. Physico-chemical aspects of the different topics are emphasized.

MS&E 532 Glass, Ceramic, and Glass-Ceramic Materials: Critical Components in Technologies
Spring. 3 credits. Offered alternate years. Staff.
The course discusses preparation of glasses and ceramics in both bulk and thin film form by conventional and unconventional techniques. Topics include hydrolysis and condensation of molecular precursors, colloids, gelation, aging, drying, and sintering. Emphasis is placed on phenomenology and modeling. Spectroscopic and scattering techniques are discussed. Synthesis and properties of nanoparticles and nanocomposites are also presented and discussed.

MS&E 541 Microprocessing of Materials
Spring. 3, 4, or 5 credits.
The previous material science course in microprocessing has been combined with EE 356 and is taught jointly with ECE. The course consists of a 2-lecture, 3-credit core course providing an introduction to the materials and processes used to fabricate integrated circuits and micro electromechanical systems. An optional extension is a hands-on, 1-credit, laboratory in which students fabricate transistors, simple integrated circuits, and MEMS structures. Students enrolled in MS&E 541 must enroll in the advanced topic, 1-credit section of the course. Enrollment in the advance credit section is optional for students registered in ECE 536. The recommended textbook is *The Science and Engineering of Microelectronic Fabrication* by Campbell. Course notes available to registered students on a password protected web site.

MS&E 542 Materials Design in Electronic Packaging
Spring. 3 credits. Staff.
Design, materials, and manufacturing needs for packaging technology from chip to board. Principles involved in key areas of materials science and other engineering disciplines. Packaging materials to be discussed include metals, ceramics, and polymers.

MS&E 543 Thin-Film Material Science
Fall. 3 credits. Offered alternate years. D. G. Ast.
This course provides fundamental information on the deposition, properties, reaction, and evaluation of thin films. Topics covered 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.

MS&E 544 Plasma Processing of Electronic Materials (also ECE 482)
Spring. 3 credits. Prerequisites: PHYS 213 and 214 or equivalent. Offered on demand. Staff.
For description, see ECE 482.

[MS&E 545 Magnetic Materials
Fall. 3 credits. Prerequisites: PHYS 213 and 214 or equivalent. Offered alternate years. Not offered 2003–2004.
This course covers the fundamentals of magnetic phenomena and specific magnetic materials and their use in modern applications. Magnetization phenomena, the origin of magnetism in a material, magnetic domains, and magnetic anisotropy are included in the fundamentals. Specific magnetic materials and their applications include ferromagnetism in thin films and fine particles, amorphous magnetic materials; magnetic recording, magnetic circuits.]

[MS&E 546 Solar Cells: Energy from the Environment
Fall. 2 or 3 credits. Lec, 2 credits. Lab, 1 credit. Laboratory enrollment is limited to 10 students. No prerequisites. Not offered fall 2003. D. G. Ast.
Solar cells provide power to satellites but are increasingly used for other applications, including the generation of electricity to power homes and even cars and airplanes. This course introduces the physics, design, manufacturing, testing, applications, and long-term reliability of solar cells. Topics include the energy distribution of the solar spectrum in space and at the surface of the earth, the physics of converting of light into electricity, the ideal conversion efficiency of solar cells, solar cell design, the economical fabrication of solar cells, testing and government regulations, and the long-term reliability of solar cells. The course covers mostly classical solid state solar cells but provides an introduction to emerging competing technologies using polymers and organic dyes. In the laboratory, students fabricate and test a solar cell. The instructor provides special recitations, as needed, for students lacking a semiconductor background but interested in the subject of solar cells. The recommended textbook is *Solar Cells, Operating Principles, Technology and Systems Applications* by Martin Green.]

MS&E 555 Introduction to Composite Materials (also CEE 475, M&AE 455, and T&AM 455)
Spring. 4 credits.
For description, see T&AM 455.

MS&E 563 Nanobiotechnology (also A&EP 663 and BIO G 663)
Spring. 3 credits.
For description, see A&EP 663.

MS&E 571 Analytical Techniques for Material Science (Also MS&E 603)
Spring. 3 credits.
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.

MS&E 572 Computational Materials Science
Spring. 3 credits. Prerequisite: MS&E 303/601 or equivalent; programming. M. O. Thompson.
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.

Graduate Professional Courses

MS&E 501–502 Special Project
501, fall; 502, spring. 6 credits each term.
Master of Engineering research project.

MS&E 582 Mechanical Properties of Materials, Processing, and Design (also MS&E 302)
Spring. 4 credits. Corequisite: MS&E 584 or permission of instructor.
For description, see MS&E 302.

MS&E 583 Thermodynamics of Condensed Systems (also MS&E 303)
Fall. 4 credits. M. O. Thompson.
For description, see MS&E 303.

MS&E 584 Kinetics, Diffusion, and Phase Transformation (also MS&E 304)
Spring. 4 credits. Prerequisite: MS&E 583 or permission of instructor.
For description, see MS&E 304.

MS&E 585 Electronic, Magnetic, and Dielectric Properties of Materials (also MS&E 305)
Fall. 4 credits. R. B. van Dover.
For description, see MS&E 305.

MS&E 587 Technology Management
Spring. 3 credits. E. P. Giannelis.
For description, see MS&E 481.

Graduate Core Courses

MS&E 601 Thermodynamics of Materials
Fall. 3 credits. Prerequisite: course in thermodynamics at level of MS&E 303. J. M. Blakely.
Topics covered include basic statistical thermodynamics, partition functions and thermodynamic state functions, distributions, laws of thermodynamics, free-energy functions and conditions of equilibrium, chemical reactions, statistics of electrons in crystals, heat capacity, heterogeneous systems and phase transitions, and lattice models of 1-, 2-, and 3-dimensional interacting systems. Also covers: statistical thermodynamics of alloys, free-energy and phase diagrams, order-disorder phenomena, point defects in crystals, and statistical thermodynamics of interfaces.

MS&E 602 Elasticity, Plasticity, and Fracture
Spring. 3 credits. Offered alternate years.
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.

MS&E 603 Analytical Techniques for Materials Science (also MS&E 571)
Spring. 3 credits.
For description, see MS&E 571.

MS&E 604 Kinetics of Reactions in Condensed Matter
Fall. 3 credits. A. L. Ruoff.
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 coarsening processes, recrystallization, and grain growth; diffusion-controlled growth, interfacial reactions, moving boundary problems; grain-boundary migration controlled kinetics; viscosity, anelasticity, and diffusional creep. Texts: (1) Shewmon, *Diffusion in Solids*, (2) Porter and Easterling, *Phase Transformations in Metals and Alloys*.

Related Course in Another Department

Introductory Solid-State Physics (PHYS 454)

Further Graduate Courses

MS&E 621 Advanced Inorganic Chemistry III: Solid-State Chemistry (also CHEM 607)
Fall. 4 credits. Prerequisite: CHEM 605 or permission of instructor. S. Lee.
For description, see CHEM 607.

MS&E 622 Synthetic Polymer Chemistry (also CHEME 675 and CHEM 671)
Spring. 4 credits. Prerequisites: CHEM 359–360 or equivalent or permission of instructor. Staff.
For description, see CHEM 671.

MS&E 631 Solid-State Reactions
Fall. 3 credits. Offered alternate years. R. Dieckmann.
Topics include point defects (thermal disorder, component-activity-dependent disorder, influence of dopants, different kinds of associates, Coulomb interaction between point defects), dislocations, grain boundaries; transport in solids (definition and different types of diffusion coefficients, reference frames, mechanisms of electrical conduction, elementary diffusion mechanisms, atomic theory of transport, correlation effects, phenomenological theory of transport including some aspects of thermodynamics of irreversible processes, Fick's laws); point-defect relaxation (migration controlled, phase-boundary-reaction controlled); inter-diffusion; solid-state reactions involving compound formation (oxidation of metals, reactions between solids); and de-mixing of materials in potential gradients, and selected solid-state processes (internal reactions, etc.).

[MS&E 632 Solid State Electrochemistry
Fall. 3 credits. Prerequisite: MS&E 631 or permission of instructor. Not offered 2003–2004. R. Dieckmann.
Topics include disorder in solids; thermodynamic quantities or quasi-free electrons and electron defects in semiconductors; mobility, diffusion, and partial conductivity of ions and electrons; solid ionic conductors, solid electrolytes, and solid solution electrodes; galvanic cells with solid electrolytes for thermodynamic investigations; and technical applications of solid electrolytes. At the level of *Electrochemistry of Solids* by H. Rickert.]

MS&E 655 Composite Materials (also M&AE 655 and T&AM 655)
Spring. 4 credits. Staff.
For description, see T&AM 655.

MS&E 665 Principles of Tissue Engineering (also M&AE 665, BMEP 665)
Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.
This course 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, nervous system, and artificial organs. These topics are discussed in the context of scale-up, manufacturing, and regulatory issues.

MS&E 671 Principles of Diffraction (also A&EP 711)
Spring. 3 credits. Letter grades only. J. D. Brock.
For description, see A&EP 711.

MS&E 672 Transmission Electron Microscopy
Spring. 3 credits. Prerequisite: MS&E 206 or equivalent. Offered alternate years.
This course covers the theory and practice of obtaining and interpreting TEM data from crystalline materials. Topics include microscope optics and conventional and high-resolution image formation. Special emphasis is placed on electron diffraction (formation and analysis of spot patterns, Kikuchi patterns, and convergent beam patterns), and obtaining useful images of crystal defects. Practical requirements for high-resolution imaging of crystal lattices and interfaces are also covered. Associated theoretical topics include kinematical and dynamical diffraction theories, the contrast transfer function theory of phase contrast, and image modeling and image analysis for quantitative interpretation of data. Current text is *Transmission Electron Microscopy* by D. B. Williams and C. B. Carter.

MS&E 681 Surfaces and Interfaces in Materials
Spring. 3 credits. Offered alternate years.
This course deals with special topics in the field of surface and interface science. Some knowledge of basic statistical thermodynamics, crystallography, elementary quantum mechanics, and theory of rate processes is assumed. The following are the main topics: 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

MS&E 800 Research in Materials Science
Fall, spring. Credit to be arranged. Staff.
Independent research in materials science under the guidance of a member of the staff.

MS&E 801 Materials Science and Engineering Colloquium
Fall and spring. 1 credit each term. Credit limited to graduate 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.

MS&E 802 Materials Science Research Seminars
Fall, spring. 2 credits each term. For graduate students involved in research projects. Staff.
Short presentations on research in progress by students and staff.

MECHANICAL AND AEROSPACE ENGINEERING

General and Required Courses

M&AE 101 Naval Ship Systems (also NAV S 202)
Spring. 3 credits.
For description, see NAV S 202.

M&AE 117 Introduction to Mechanical Engineering (also ENGRI 117)
Fall. 3 credits. 2 lectures and 1 lab per week.
This is a course in the Introduction to Engineering series. For description, see ENGRI 117.

M&AE 127 Introduction to Entrepreneurship and Enterprise Engineering (also ENGRI 127)
Spring. 3 credits. Open to all Cornell students regardless of major. No prerequisites.
For description, see ENGRI 127

M&AE 212 Mechanical Properties and Processing of Engineering Materials
Spring. 4 credits. Prerequisite: ENGRD 202 (strictly enforced). Software fee.
Introduction to the broad range of mechanical behavior of engineering materials and their processing. Origins of mechanical properties: atomic bonding and crystalline structures, point and line defects, plastic deformation of crystals and polycrystals; strain-hardening behavior and basic elements of plasticity. Fundamentals of thermal processing are introduced including the development of equilibrium microstructures in metals and time-dependent phase transformations. Bulk deformation processes are introduced including the ideal work and slab analysis methods. General failure of materials and materials selection topics are explored. The laboratory component of the course introduces students to the fundamentals of mechanical testing and thermal processing as well as instrumentation using common engineering transducers such as strain gages and thermocouples.

M&AE 221 Thermodynamics (also ENGRD 221)
Fall, spring, may be offered summer. 3 credits. Prerequisites: MATH 192 and PHYS 112.
For description, see ENGRD 221.

M&AE 225 Mechanical Synthesis
Spring. 4 credits. Prerequisite: ENGRD 202. Pre- or corequisites: ENGRD 203 and ENGRD 221. Lab fee.
A hands-on introduction to the mechanical design process. Basic prototyping skills developed using machine tools. Mechanical dissection used to demonstrate successful product design and function. Design projects provide experience from conceptualization through prototype construction and testing. Basic instruction on CAD and technical sketching.

M&AE 323 Introductory Fluid Mechanics
Fall. Usually offered in Engineering Cooperative Program also. 4 credits. Prerequisites: ENGRD 202 and 203 and coregistration in 221, or permission of instructor.
Topics covered 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.

M&AE 324 Heat Transfer
Spring. May also be offered in Engineering Cooperative Program. 3 credits. Prerequisite: M&AE 323 or permission of instructor.
Topics include steady and unsteady heat conduction; forced and free convection; external and internal flows; radiation heat exchange; mass transfer boiling and condensation. Heat exchangers and fins. Thermophysical transport properties. First law and rate equations are developed for heat transport processes in energy systems, including applications in propulsion and power, thermal environmental control, and manufacturing.

M&AE 325 Mechanical Design and Analysis
Fall. Usually offered in Engineering Cooperative Program also. 4 credits. Prerequisites: ENGRD 202, ENGRD 203, M&AE 212, and M&AE 225. Lab fee.
Application of the principles of mechanics and materials to problems of analysis and design of mechanical components and systems.

M&AE 326 System Dynamics
Spring. May be offered in Engineering Cooperative Program. 4 credits. Prerequisite: MATH 294, ENGRD 203. Junior standing required.
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.

M&AE 427 Fluids/Heat Transfer Laboratory
Fall. 3 credits. Prerequisites: M&AE 323, 324. Fulfills the technical writing requirement.
Laboratory exercises in methods, techniques, and instrumentation used in fluid mechanics and the thermal sciences. Measurements of flame temperature, pressure, heat transfer, viscosity, lift and drag, fluid-flow rate, effects of turbulence, air foil stall, flow visualization, and spark ignition engine performance. Biweekly written assignments.

M&AE 428 Seminar on Engineering Design
Fall. 2 credits. Prerequisite: completion of 6 semesters in mechanical engineering or equivalent. S-U grades only.
This course is offered to illustrate the design "process" in action. It consists of formal lectures and invited seminars by industrial and academic practitioners of design. Case studies are presented in weekly invited lectures from a wide range of disciplines, including thermo-fluid processes, manufacturing, energy, mechanical design, aerospace, and biological sciences. The invited lectures are supplemented by one or more design "projects" in the semester.

M&AE 591 Applied Systems Engineering I (also CEE 504, COM S 504, ECE 512, OR&IE 512, SYSEN 510)
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor.
For description see SYSEN 510.

M&AE 592 Applied Systems Engineering II (also CEE 505, COM S 505, ECE 513, OR&IE 513, SYSEN 510)
Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 591, or OR&IE 512, SYSEN 510).
For description see SYSEN 520.

Mechanical Systems, Design, Materials Processing, and Precision Engineering

[M&AE 103 Introduction to Computer Aided Manufacture (CAM)
Fall, spring. 1 credit, approximately 8 weeks (total 15 hrs. of instruction and 15 hrs. of lab). Prerequisite: M&AE 225, equivalent experience, or permission of instructor. Limited enrollment. Not offered 2003–2004.
M&AE 103 introduces students to the fundamentals of computer-aided manufacture (CAM) through the use of computer numerical control (CNC) programming using G codes and solid modeling software. Students learn setup, tool selection, and operation of CNC mills and lathes. They also receive an introduction to the CNC machine tool as an electro-mechanical system. This course is required for students wishing to use the CNC equipment in the Emerson Lab's Product Realization Facility for team or research projects.]

M&AE 378 Mechatronics
Fall. 4 credits. Prerequisite: MATH 294, or permission of instructor. Limited enrollment.
Analog circuits, passive and active components, filter design, transistors, diodes, and power amplifiers are covered. Other topics include: electromagnetic systems, piezoelectric and shape memory material transduction, gear trains, pulse width modulation, optical encoders, A/D and D/A conversion, discretization, aliasing, microprocessors, and programming. Laboratory experiments culminate in a controlled robotic vehicle project.

M&AE 386 Automotive Engineering
Spring. 3 credits. Prerequisite: M&AE 325 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. Co-meets with M&AE 486.

M&AE 409 Data Structures and Algorithms for Computational Science (also CIS 409)
Fall. 4 credits. Prerequisite: COM S 100 or programming experience in any language.
For description, see CIS 409.

[M&AE 412 Smash and Crash: Mechanics of Large Deformations
Fall. 4 credits. Prerequisites: M&AE 212, T&AM 202. Fulfills field design requirement. Not offered 2003–2004.

Severe loading is a defining feature of both materials processing and crash worthiness. Materials are stressed beyond their elastic limits intentionally, resulting in large permanent deformations. In materials processing, the desire is to change a work piece shape to manufacture a component; in crash worthiness, the intent is to absorb a vehicle's energy and to protect its occupants. In this course the fundamentals of plasticity are covered: yielding, flow laws, work hardening. Various solution methods, including bound theorems, are presented. The fundamentals are applied to a number of topics in materials processing and crash design. The laboratory experience deals with these topics, culminating with the team design, construction, and testing of a crash cage.]

M&AE 415 GPS: Theory and Design (also ECE 415)

Fall. 4 credits. Prerequisites: a 300-level engineering course with advanced math content such as ECE 301, ECE 303, or M&AE 326.

For description, see ECE 415.

M&AE 417 Introduction to Robotics: Dynamics, Control, Design

Spring. 3 credits.

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, differential relationships and static forces, manipulator dynamics, trajectory generation, sensors and actuators, trajectory control, and compliant motion control. Simulation and design using MATLAB and multi-body codes are used.

M&AE 425 FSAE Automotive Design Project

Fall, spring. 3 or 4 credits. Intended for M&AE or ECE juniors and seniors or by arrangement with instructor. Usually 3 credits. Permission of instructor only.

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.

M&AE 426 FSAE Auto Design Project (Design Option)

Fall, spring. 3 or 4 credits. Limited to M&AE seniors; permission of instructor only.

Senior design version of M&AE 425. For description, see M&AE 425.

M&AE 440 Hybrid Electric Vehicle

Fall, spring. 3 credits for team members; 4 credits for team leaders. Enrollment limited to a maximum of 4 semesters. Permission of instructor only.

Team work on the design and fabrication of a hybrid vehicle for national competition.

M&AE 441 Hybrid Electric Vehicle (Design Option)

Fall, spring. 3 or 4 credits. Limited to M&AE seniors; permission of instructor only.

Senior design version of M&AE 440. For description, see M&AE 440.

M&AE 455 Introduction to Composite Materials (also CEE 475, MS&E 555, and T&AM 455)

Spring. 4 credits.

For description, see T&AM 455.

M&AE 461 Entrepreneurship for Engineers (also ENGRG 461 and OR&IE 452)

Fall. 3 credits. Enrollment open to upper class engineers; others with permission of instructor Limited enrollment.

This course 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.

[M&AE 463 Neuromuscular Biomechanics (also BMEP 463)

Spring. 3 credits. Prerequisites: ENGRD 202 and 203 or permission of instructor. Offered alternate years. Not offered 2003–2004.

Modeling and simulation of biomechanical systems using mechanics, dynamics, and control principles. Physiology of neurons and muscles introduced and related to the production of force and movement in biological systems. Representation of neuromuscular systems as simultaneous equations. Exploration of the muscular redundancy problem using optimization methods and general-purpose languages (such as *Mathematica* or MATLAB). Selected clinical applications.]

M&AE 464 Orthopaedic Tissue Mechanics

Spring. 3 credits. Prerequisites: ENGRD 202 and M&AE 325 or permission of instructor. Offered alternate years.

Applications of mechanics and materials principles to orthopaedic tissues. Physiology of bone, cartilage, ligament, and tendon introduced and related 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.

M&AE 466 Biomedical Engineering Analysis of Metabolic and Structural Systems (also BMEP 401)

Fall. 3 credits. Prerequisite: prior course work in basic biology.

For description, see BMEP 401.

M&AE 470 Finite Element Analysis for Mechanical and Aerospace Design

Spring. 3–4 credits. (4 credits as M&AE design elective for M&AE seniors) Prerequisite: senior standing or permission of instructor. Limited enrollment. Evening examinations. Term project. Fulfills senior design requirement for M&AE students.

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. Co-meets with M&AE 570.

M&AE 477 Engineering Vibrations

Spring. 3 credits. Prerequisite: M&AE 326 (or co-registration), 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 M&AE 577.

M&AE 478 Feedback Control Systems (also CHEME 472, ECE 472)

Spring. 4 credits. Prerequisites: one of the following: CHEME 372, ECE 301, M&AE 326, 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.

M&AE 479 Modeling and Simulation of Mechanical and Aerospace Systems

Fall. 3 credits. Prerequisite: senior engineering standing or permission of instructor. Evening examinations. Term project. Fulfills M&AE senior design elective. Limited enrollment. F. Valero-Cuevas.

Analysis and simulation of linear and nonlinear systems. Representation of discrete and distributed dynamical systems by state-variable models. Time- and frequency-domain simulation via general-purpose languages (such as MATLAB or Mathematica) and special-purpose simulation software (such as Simulink). Selected applications from diverse fields. Co-meets with M&AE 579.

M&AE 486 Automotive Engineering Design

Spring. 4 credits. Prerequisite: senior standing. Fulfills field senior design requirement for M&AE students.

For description, see M&AE 386.

M&AE 514 Design for Manufacture and Assembly

Fall or spring. 4 credits. Prerequisites: M&AE 212 or 412, and introductory probability and statistics, or permission of instructor.

Nominal DFMA (design for manufacture and assembly) and variational DFMA are covered in two parallel streams. The nominal stream is based on readings in a popular text that surveys the role of manufacturing and assembly processes in part and product design. The second stream, covered mainly through lectures, addresses dimensional variability and its control through parametric and geometric tolerances, dimensional metrology, and statistical quality and process control.

M&AE 525 Mechatronics Systems Engineering Project

Fall, spring. 4 credits each term (must be taken for 8 credits). Limited enrollment; engineering seniors and Master of Engineering students only. Corequisite: Applied Systems Engineering I or permission of instructor. Fulfills Master of Engineering project requirement, Systems Engineering Option project requirement, and undergraduate senior design elective.

Project-based introduction to systems engineering with a focus on system design, systems and technology integration, and systems analysis. Approximately 30 students from the various engineering disciplines design, construct, and fully test several teams of fully autonomous, mobile robots. These teams engage in head to head competitions at the end of the spring semester. There are approximately six lectures per semester and weekly group meetings with the instructor. The project involves vehicle design, real-time feedback control and trajectory generation, microprocessor design and implementation, wireless communication, computer vision, and artificial intelligence.

M&AE 565 Biomechanical Systems—Analysis and Design (also BMEP 565)

Fall. 3 or 4 credits. Prerequisites: undergraduate courses in dynamics and strength of materials, (e.g., T&AM/ENGRD 202 and 203) and senior standing, graduate standing, or permission of instructor.

Mechanics and design in musculoskeletal systems. Emphasis on the modeling and analysis of bones and joints and the analysis and design of bone-implant systems for fracture fixation and joint replacement. Selected topics from the study of the human musculoskeletal system as a mechanical system. Emphasis on the modeling and analysis of bones and joints, and the analysis and design of biomechanical systems frequently encountered in orthopaedic engineering, including bone-implant systems.

M&AE 570 Simulation of Mechanical and Aerospace Systems (also M&AE 470)

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Evening examinations. Term project.

Graduate version of M&AE 470. For description, see M&AE 470. Co-meets with M&AE 470.

M&AE 571 Applied Dynamics

Fall. 3 credits. Prerequisites: graduate standing, seniors with T&AM/ENGRD 203, M&AE 326 or permission of instructor. 2 lectures.

Introduction to 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.

M&AE 577 Engineering Vibrations

Spring. 3 credits. Prerequisite: M&AE 326 or equivalent, graduate standing, or permission of instructor. Graduate version of M&AE 477.

For description, see M&AE 477.

M&AE 579 Modeling and Simulation of Mechanical and Aerospace Systems

Fall. 3 credits. Prerequisite: graduate standing or permission of instructor. Limited enrollment. Evening examinations. Term project. Graduate version of M&AE 479.

For description, see M&AE 479.

[M&AE 613 Simulation Methods in Mechanics of Materials

Spring. 4 credits. Prerequisite: M&AE 612 or TAM 663, programming experience in Matlab, FORTRAN, or C; introductory finite element course recommended. Offered alternate years. Not offered 2003–2004.

Presentation of mechanics framework for simulations of large plastic deformations. Discussion of state variable theories for the constitutive description of mechanical behavior of solids. Presentation of finite element formulations for solving problems that include nonlinearities from large deformations and inelastic behaviors. Coverage of several numerical issues, including consistent computational formulations, error estimation, adaptive meshing, and contact algorithms. Applications in polymer processing, metal forming, micromechanics, and inelastic design.]

[M&AE 615 Mechanics of Materials: Experiments and Simulations

Fall. 4 credits. Prerequisite: M&AE 680 (finite elements) or permission of instructor. Not offered 2003–2004.

This course focuses on experiments and simulations related to the mechanical properties of materials and materials processing. A general introduction to sensors and instrumentation for engineering measurements is also included. Testing for mechanical properties/model parameter characterization and simple boundary value problems: linear elasticity, inelastic deformation, fatigue, and fracture, including rate and temperature effects. Process simulation experiments including forging, extrusion, rolling, and ironing may also be conducted. In addition, an emphasis is placed on the experiment/simulation interface. Students perform analyses including finite element modeling to correlate and predict materials behaviors observed in the experiments. These analyses include linear elasticity behavior, state variable plasticity modeling, and fracture mechanics.]

M&AE 655 Composite Materials (also MS&E 655 and T&AM 655)

Spring. 4 credits.

For description, see T&AM 655.

M&AE 663 Advanced Topics in Neuromuscular Biomechanics (also BMEP 663)

Spring. 3 credits. Permission of instructor only. Offered alternate years. F. Valero-Cuevas.

Advanced topics in modeling and simulation of biomechanical systems using mechanics, dynamics, and control principles. Mathematical representation of the functional interactions among neurons, muscles, and skeletal structures. Numerical prediction of force and movement in biological systems, and projects exploring muscle coordination using optimization methods and general-purpose languages (such as Mathematica or MATLAB). Project-based investigation of clinically relevant topics.

[M&AE 664 Mechanics of Bone

Spring. 3 credits. Prequisites: graduate standing or permission of instructor. Offered alternate years. Not offered 2003–2004.

This course focuses on 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.]

M&AE 665 Principles of Tissue Engineering (also BMEP 665 and MS&E 665)

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. L. Bonassar.

See BMEP 665 for description.

M&AE 675 System Identification and Control

Fall. 3 credits. Prerequisite: M&AE 478/ECE 471/CHEME 472, M&AE 521/ECE 521, or equivalent.

Covers the identification of linear uncertain and nonlinear models and their connections to control. Black box methods, such as subspace methods, and model tuning approaches, such as recursive parameter estimation, are presented. Connections to control include the development of model uncertainties and bounds and control approaches consistent with identified models. Current trends in model identification for control are discussed. Other topics, such as hybrid models, are presented given enough time.

M&AE 676 Model-Based Estimation

Fall. 4 credits. Prerequisites: linear algebra, differential equations, and MATLAB programming. Open to M.S./Ph.D.; others by permission of the instructor.

This course 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.

[M&AE 677 Robust and Optimal Control

Spring. 4 credits. Prerequisite: M&AE 478/ECE 471/CHEME 472 (or equivalent), ECE 521 (or equivalent), graduate standing, or permission of instructor. Not offered 2003–2004.

An introduction to model based control of multi-input, multi-output systems. Emphasis on design techniques that result in closed loop systems that are insensitive to modeling errors and that achieve a pre-specified level of performance. Topics include Lp spaces and performance measures, model reduction and approximation, H2 and H-infinity optimal control, explicit models of system uncertainty, and the analysis of uncertain control systems. Most of the design and analysis tools developed in the course are in the form of linear matrix inequalities or semidefinite programs. Each student is expected to: (1) give a presentation on a research paper, which is chosen from a list provided by the instructor, **or** (2) to complete a design project applying the techniques developed in the course.]

M&AE 680 Finite Element Analysis (also CEE 676 and T&AM 666)

Spring. 3 credits. Prerequisites: T&AM 663 and T&AM 610 or equivalent.

Conceptual, theoretical, and practical bases for finite element analysis in engineering, with emphasis on structural, mechanical, and thermal problems. Focuses on the FEM as a method for numerically solving partial differential equations. Topics include: strong and weak problem forms; weighted-residual and variational formulations; formulations for elliptic, parabolic, and hyperbolic problems (Laplace's equation, elasticity, heat conduction, structural dynamics, wave propagation); meshing and error estimation; and various kinds of elements.

[M&AE 712 Mechanics of Materials with Oriented Microstructures

Spring. 4 credits. Prerequisites: T&AM 663 and M&AE 680 (or equivalents). Second year standing in MS/Ph.D. program. Offered alternate years. Not offered 2003–2004.

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.]

Energy, Fluids, and Aerospace Engineering

M&AE 305 Introduction to Aeronautics

Fall. 3 credits. Prerequisite: T&AM/ENGRD 203; limited to upperclass engineers, others with 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, stability, and control. Description and performance of reciprocating and jet propulsion engines; propeller theory.

M&AE 306 Spacecraft Engineering

Spring. 3 credits. Junior and senior engineering students.

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.

[M&AE 400 Components and Systems: Engineering in a Social Context (also S&TS 400)

Fall. 3 credits. Prerequisites: upperclass standing, 2 years of college physics. Serves as an approved elective but not as a Field Elective in Mechanical Engineering. Not offered 2003–2004.

This course 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, we investigate interactions between the scientific, technical, political, economic, and social forces that are involved in the development of engineering systems.]

[M&AE 401 Components and Systems: Engineering in a Social Context

Fall. 4 credits. Prerequisites: senior standing, 2 years of college physics. Fulfills M&AE senior field design requirement. Not offered 2003–2004.

For description, see M&AE 400.]

M&AE 423 Intermediate Fluid Dynamics

Spring. 3 credits. Prerequisite: M&AE 323. Fulfills Computer Application Elective for M&AE students.

This course builds on the foundation of M&AE 323. 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 covered include some exact solutions to the Navier-Stokes equations, boundary layers, wakes and jets, separation, convection, stratified and rotating flows, fluid instabilities, and turbulence.

M&AE 449 Combustion Engines

Spring. 3 credits. Prerequisites: ENGRD 221 and M&AE 323.

Introduction to combustion engines, with emphasis on the application of thermodynamic and fluid-dynamic principles affecting their performance. Chemical equilibrium and kinetics, ideal-cycle analyses, deviations from ideal processes, engine breathing, combustion, knock. Formation and control of undesirable exhaust emissions.

M&AE 453 Computer-Aided Engineering: Applications to Biomedical Processes (Also BEE 453)

Spring. 3 credits. Prerequisite: heat and mass transfer (BEE 350 or equivalent).

Fulfills computer applications elective for M&AE students. See BEE 453 for description.

M&AE 458 Introduction to Nuclear Science and Engineering (also ECE 413)

Fall. 3 credits. Prerequisites: PHYS 214 and MATH 294.

For description, see ECE 413.

M&AE 459 Introduction to Controlled Fusion: Principles and Technology (also A&EP 484 and ECE 484)

Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics. Intended for seniors and graduate students in Engineering and the physical sciences. Offered alternate years. Offered spring 2004.

For description, see NS&E 484.

M&AE 501 Future Energy Systems

Spring. 3 credits. Prerequisites: ENGRD 221, M&AE 323, M&AE 326, or equivalents. Open to graduate and upperclass students or approval from instructor.

Critically examines the technology of energy systems that will be acceptable in a world faced with global warming, 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 as well as the overall systems are analyzed.

M&AE 506 Aerospace Propulsion Systems

Fall. 3 credits. Prerequisite: M&AE 323 or permission of instructor. Offered alternate years.

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.

[M&AE 507 Dynamics of Flight Vehicles

Spring. 3 credits. Prerequisites: M&AE 305 and M&AE 323 or permission of instructor. Offered alternate years. Not offered 2003–2004.

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 *Dynamics of Flight: Stability and Control* by Etkin.]

M&AE 523 Intermediate Fluid Dynamics with CFD

Spring. 4 credits. Prerequisites: graduate standing or permission of instructor.

This course is intended for M.Eng. students who wish to take a single fluid dynamics course. Students desiring more intensive treatment should consider M&AE 601 and one or more of M&AE 636, M&AE 736, and M&AE 737. This class co-meets with M&AE 423. In addition to the normal requirements for M&AE 423, this course includes an extensive CFD design project.

M&AE 543 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, droplet combustion, and combustion of solids.

M&AE 601 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.

M&AE 602 Fluid Dynamics at High Reynolds Numbers

Spring. 4 credits. Prerequisite: M&AE 601. Offered alternate years.

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. Various stability problems associated with high Reynolds number flows are discussed. Finally, certain low Reynolds number flows associated with creeping motions or with ultra-small scale will be described.

[M&AE 603 Compressible Fluid Dynamics

Fall. 4 credits. Graduate standing or permission of instructor. Not offered 2003–2004.

Fundamentals of compressible gas dynamics are described using thermodynamics and fluid properties, together with isentropic and viscous andulseous flow theories; normal and oblique shock-waves; Prandtl-Meyer expansion fans; sound waves and acoustics; and duct flows including effects of area, friction, and heat interaction. Applications include high-speed aerodynamics, including hypersonics combustor design.]

M&AE 608 Physics of Fluids

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years.

Behavior of a gas is considered at the microscopic level. Introduction to kinetic theory: velocity distribution, collisions, Boltzmann equation. Quantum theory: postulates of quantum mechanics, internal structure, rigid rotator, harmonic oscillator, one-electron atom. Statistical mechanics: partition functions, relation to thermodynamics, calculations of thermodynamic properties. Chemical rate processes.

M&AE 631 Turbulence and Turbulent Flows

Fall. 4 credits. Prerequisite: M&AE 601, 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.

M&AE 632 Multiphase Turbulence: Particulates, Drops and Polymer Suspensions

Spring. 4 credits. Prerequisites: M&AE 601, graduate standing, or permission of instructor.

The course will cover turbulent transport of suspensions of microstructures: (i) particulates; (ii) drops; and (iii) polymer molecules. Topics include transport properties of individual microstructures, statistical averaging and the closure problem, Euler/Lagrangian methods, multiphase transport equations, direct numerical simulation and large eddy simulation. The course emphasizes fundamental questions concerning modeling of discrete phases by continuum means.

[M&AE 636 Elements of Computational Aerodynamics

Fall or spring. 4 credits. Prerequisites: graduate standing and a graduate-level course in fluid mechanics. Not offered 2003–2004.

Topics relevant to numerical solution of problems in aerodynamics and fluid mechanics. Analysis and application of computational techniques appropriate for solution of inviscid or high Reynolds number fluid flow problems. Course has common lectures with M&AE 736 but is more applications oriented and uses commercial software for all computational exercises.]

M&AE 643 Computational Combustion

Spring. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. S. B. Pope.

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 M&AE 543, Combustion Processes, is useful but not required.

[M&AE 645 Turbulent Reactive Flow

Spring. 3 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. Not offered 2003–2004.

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.]

[M&AE 650 Evolutionary Computation and Design Automation (Also COM S 750, CIS 750)

Fall. 4 credits. Not offered 2003–2004.

For description, see COM S 750.]

M&AE 651 Conduction and Radiation Heat Transfer

Fall, weeks 1–7. 2 credits. Prerequisite: graduate standing; undergraduates by permission of instructor.

An intermediate treatment of heat conduction and thermal radiation. Deductions from the first and second laws of thermodynamics. The conductive transport equation. Physical mechanism of thermal conductivity. Steady, transient, and some multidimensional conduction. The radiative transport equation. Surface and gas radiation properties. Radiant exchange between surfaces and volumes. Molecular and particulate scattering. Radiosity and volume integral formulations. At the level of, but extends, *Heat Transfer* by Bejan.

M&AE 652 Convection Heat Transfer

Fall, weeks 8–14. 2 credits. Prerequisite: graduate standing; undergraduates by permission of instructor.

An intermediate treatment of convection heat transfer. Governing equations developed in integral and differential forms. Boundary layers. Laminar and turbulent flows. Internal and external, forced and free convection. Entropy and system arguments for optimal design. Parameter identification. At the level of, but extends, *Heat Transfer* by Bejan.

[M&AE 714 Computational Sensorics: Information Technologies for Complex Continuum Systems

Fall. 4 credits. Prerequisites: exposure to computational mathematics. Some background in continuum systems and processes such as fluid flow, thermal transport and/or deformation of materials/structures. Not offered 2003–2004. N. Zabaras.

Syllabus: examples of industrial control of continuum systems; mathematical preliminaries; finite element approach to partial differential equations; inverse problems and inverse problem solving; optimal control problems; numerical analysis of distributed control problems; reduced-order models for continuum systems; feedback laws for continuum systems; robust control and uncertainty; data mining of continuum systems and models; data compression and transmission techniques; advanced adaptive sensing and actuation of continuum fields.]

[M&AE 733 Stability of Fluid Flow

Fall, on demand. 4 credits. S-U grades only. Prerequisite: graduate standing or permission of instructor. Not offered 2003–2004.

Basic stability and bifurcation theory in fluid systems. "Open" flow systems: inviscid Kelvin-Helmholtz, Rayleigh-Taylor instability, and capillary instability of liquid jets. Stability of parallel shear flows and of concentrated vortex flows. Spatial development of linearly unstable motion: "absolute" and "convective" instability. Thermal, double-diffusive, and related instabilities. Post-bifurcation behavior: the Ginzburg-Landau (Stewartson-Stuart) and Davey-Hocking-Stewartson amplitude equations. Phase dynamics and pattern formation. Stability of periodic motion: Floquet theory. Secondary instabilities; Eckhaus instability, Busse "balloons." Energy stability theory. Effects of symmetry. Taylor-Couette instability.]

[M&AE 734 Analysis of Turbulent Flows

Spring. 4 credits. Prerequisite: M&AE 601 or permission of instructor. Offered alternate years. Not offered 2003–2004.

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 (pdf's): transport equations, relationship to second-order closures, stochastic modeling, and the Langevin equation. Large-eddy simulations: filtered and residual motions, Smagorinsky, and dynamic models. The course emphasizes comparison of theory with experiment.]

[M&AE 736 Theory of Computational Aerodynamics

Fall. 4 credits. Prerequisites: graduate standing, an advanced course in continuum mechanics or fluid mechanics, and some higher-level (FORTRAN, MATLAB, etc.) programming experience. Not offered 2003–2004.

Numerical methods to solve inviscid and high-Reynolds-number fluid-dynamics problems, including finite-difference, finite-volume, and surface-singularity methods. Accuracy, convergence, and stability; treatment of boundary conditions and grid generation. Focus on hyperbolic (unsteady flow with shock waves) and mixed hyperbolic-elliptic (steady transonic flow) problems. Assignments require programming a digital computer.]

M&AE 737 Computational Fluid Mechanics and Heat Transfer

Fall. 4 credits. Prerequisites: graduate standing; an 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.

Special Offerings

M&AE 490 Special Investigations in Mechanical and Aerospace Engineering

Fall, spring. Credit TBA. Limited to undergraduate students. Prerequisite: 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.

M&AE 491 Design Projects in Mechanical and Aerospace Engineering

Fall, spring. Credits TBA. Prerequisite or corequisite: M&AE 428. Fulfills field design requirement.

Intended for individual students or small groups of students who want to pursue particular design projects outside of regular courses. Students should adhere to the design process and documentation guidelines available at the M&AE undergraduate office.

M&AE 545 Energy Seminar (also ECE 587, MS&E 545)

Fall, spring. 1 credit. May be taken for credit both semesters.

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. Examples of topics to be surveyed include energy resources and economics; coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; and air pollution control.

M&AE 594 Enterprise Engineering Colloquium (also OR&IE 893–894)

Fall, spring. 1 credit.

For description, see OR&IE 893–894.

M&AE 690 Special Investigations in Mechanical and Aerospace Engineering

Fall, spring. Credit TBA. Limited to graduate students.

M&AE 695 Special Topics in Mechanical and Aerospace Engineering

Fall, spring. Credit TBA. Graduate standing and permission of instructor.

Special lectures by faculty members on topics of current research.

M&AE 791 Mechanical and Aerospace Research Conference

Fall, spring. 1 credit each term. S-U grades only. For graduate students involved in research projects.

Presentations on research in progress by faculty and students.

M&AE 799 Mechanical and Aerospace Engineering Colloquium

Fall, spring. 1 credit each term. Credit limited to graduate students. All students and staff 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.

M&AE 890 Research in Mechanical and Aerospace Engineering

Credit TBA. Prerequisite: candidacy for M.S. degree in mechanical or aerospace engineering or approval of director.

Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

M&AE 990 Research in Mechanical and Aerospace Engineering

Credit TBA. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval of director.

Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

NUCLEAR SCIENCE AND ENGINEERING

NS&E 121 Fission, Fusion, and Radiation (also A&EP 121 and ENGRI 121)

Spring. 3 credits. S-U grades optional for students outside the College of Engineering. K. B. Cady.

This is a course in the Introduction to Engineering series. For description, see ENGRI 121.

[NS&E 484 Introduction to Controlled Fusion: Principles and Technology (also A&EP 484, ECE 484, and M&AE 459)

Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students. Not offered 2003–2004. D. A. Hammer.

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.]

NS&E 509 Nuclear Physics for Applications

Fall. 3 credits. Prerequisites: sophomore physics and math or permission of instructor; some upper-division physics is desirable. Primarily for graduate students, especially those with a major or minor in Nuclear Science and Engineering; also open to qualified undergraduates. V. O. Kostroun.

A first course in nuclear physics. Systematic presentation of nuclear phenomena and processes that underlie applications ranging from nuclear power (fission and fusion), to nuclear astrophysics, to nuclear analytical methods for research in nonnuclear fields. Radioactivity, nuclear reactions, and interaction of radiation with matter. At the level of *Radiochemistry and Nuclear Methods of Analysis* by Ehmann and Vance and *Nuclear and Radiochemistry* by Friedlander, et al.

NS&E 545 Energy Seminar (also ECE 587 and M&AE 545)

Fall, spring. 1 credit. May be taken for credit both semesters. E. Fisher.

For description, see ECE 587.

NS&E 590 Independent Study

Fall, spring. 1–4 credits. Grade option letter or S-U. Staff.

Independent study or project under guidance of a faculty member.

NS&E 591 Project

Fall, spring. 1–6 credits. Staff.

Master of Engineering or other project under guidance of a faculty member.

NS&E 612 Nuclear Reactor Theory

Fall. 4 credits. Prerequisites: 1 year of advanced calculus and some nuclear physics. Offered on demand. K. B. Cady.

Physical theory of fission reactors; fission and neutron interactions with matter; theory of neutron diffusion; slowing down and thermalization; calculations of criticality and neutron-flux distribution in nuclear reactors; and reactor kinetics. At the level of *Nuclear Reactor Theory* by Lamarsh.

NS&E 633 Nuclear Reactor Engineering (also A&EP 633)

Fall. 4 credits. Prerequisite: introductory course in nuclear engineering. Offered on demand. K. B. Cady.

The fundamentals of nuclear reactor engineering, reactor siting and safety, fluid flow and heat transfer, control, environmental effects, and radiation protection.

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

OR&IE 310 Industrial Systems Analysis

Spring. 4 credits. Prerequisite or corequisite: ENGRD 270 or permission of instructor. J. Callister.

Design of production facilities, including engineering economy, materials handling, process design, and facility layout. Covers operations analysis, including process scheduling, process evaluation, procedural analysis, project management, methods analysis and design, work measurement, inventory control, job evaluation, and quality engineering and control.

OR&IE 320 Optimization I

Fall. 4 credits. Prerequisite: MATH 221 or 294. J. Renegar.

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.

OR&IE 321 Optimization II

Spring. 4 credits. Prerequisite: OR&IE 320 or equivalent. L. Trotter.

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.

OR&IE 350 Financial and Managerial Accounting

Fall. 4 credits. J. Callister.

Course 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.

OR&IE 360 Engineering Probability and Statistics II

Fall. 4 credits. Prerequisite: ENGRD 270 or equivalent. G. Samorodnitsky.

This second course in probability and statistics provides 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.

OR&IE 361 Introductory Engineering Stochastic Processes I

Spring. 4 credits. Prerequisite: OR&IE 360 or equivalent. K. B. Athreya.

Basic concepts and techniques of random processes are used 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.

OR&IE 416 Design of Manufacturing Systems

Fall. 4 credits. Senior OR&IE students only. Others by permission of instructor only. P. Jackson/J. Muckstadt.

This is a 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 advisers are substituted for some lectures. Analytical methods for controlling inventories, planning production, and evaluating system performance are presented in lectures.

OR&IE 431 Discrete Models

Fall. 4 credits. Prerequisites: OR&IE 320 and COM S 211 or permission of instructor. D. Shmoys.

Course 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.

[OR&IE 432 Nonlinear Optimization

Fall. 4 credits. Prerequisite: OR&IE 320. Not offered 2003–2004.

This course is an introduction to the practical and theoretical aspects of nonlinear optimization. Attention is given to the computational efficiency of algorithms and the application of nonlinear techniques to linear programming; e.g., interior-point methods. Methods of numerical linear algebra are introduced as needed.]

[OR&IE 434 Optimization Modeling

Spring. 3 credits. Prerequisites: a grade of at least B- in OR&IE 321/521. Not offered 2003–2004.

Emphasis is on 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.]

OR&IE 435 Introduction to Game Theory

Fall. 3 credits. E. Friedman.

A 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.

OR&IE 436 A Mathematical Examination of Fair Representation

Spring. 3 credits. Prerequisites: MATH 222 or 294 or permission of instructor. R. Bland.

This course 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. At first blush it appears that there is a straightforward approach that must lead to a fair, or fairest apportionment, for any fixed house size and known populations. However, 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 some other realms where indivisible resources are to be allocated among competing constituencies.

OR&IE 451 Economic Analysis of Engineering Systems

Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.

Course 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.

OR&IE 452 Entrepreneurship for Engineers (also MAE 461 and ENGRG 461)

Fall. 3 credits. Enrollment open to upper-class engineers, others by permission of instructor. J. Callister.

For description see MAE 461.

[OR&IE 462 Introductory Engineering Stochastic Processes II

Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Not offered 2003–2004.

Course 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.]

OR&IE 464 Extreme Value Analysis with Applications to Finance and Data Communications

Spring. 3 credits. Prerequisites: open to undergraduate and M.Eng. students who have had a stochastic processes course at the level of OR&IE 361 as well as a prior course in statistics. S. Resnick.

The course will cover the basic models of extreme events used in hydrology, finance, insurance, environmental science (pollution controls), reliability, risk management. The basic models contain parameters that must be estimated, and graphical and analytic estimation methods are discussed. Extreme quantiles and very small excedence probabilities need to be estimated, and usually the part of a distribution tail which is way beyond the range of the data needs to be considered. This leads to discussion of estimation needed for VAR (value-at-risk) calculations. The course material intersects the related field of heavy tailed modeling and the implications of heavy tails in insurance and data networks.

OR&IE 467 Credit Risk: Modeling, Valuation, and Management

Spring. 4 credits. Prerequisite: OR&IE 361. K. Giesecke.

Credit risk refers to losses due to changes in the credit quality of a counter party in a financial contract. The course is an introduction to the modeling and valuation of credit risks. Emphasis will be on credit derivative instruments used for hedging credit risks, including credit swaps, spread options, and collateralized debt obligations.

OR&IE 468 Financial Engineering with Stochastic Calculus I

Fall. 4 credits. Prerequisite: knowledge of probability at the level of OR&IE 360. K. Giesecke.

This course is an 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.

[OR&IE 469 Financial Engineering with Stochastic Calculus II

Spring. 4 credits. Prerequisite: OR&IE 468/568. Not offered 2003–2004.

Building on the foundation established in OR&IE 468/568, 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.]

OR&IE 473 Operations Research Tools for Financial Engineering.

Spring. 3 credits. Prerequisites: engineering math through MATH 294 and OR&IE 270 and 360. D. Ruppert.

This course is an introduction to the applications of OR techniques, e.g., probability, statistics, and optimization, to finance and financial engineering. No previous knowledge of finance is required. The course 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. The use of MATLAB, MINITAB, and SAS for computation is also covered.

OR&IE 474 Statistical Data Mining

Fall. 3 credits. Prerequisites: OR&IE 360 and MATH 294 or equivalent; or permission of instructor.

This course 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.

OR&IE 476 Applied Linear Statistical Models

Spring; weeks 1–7. 2 credits. Prerequisite: ENGRD 270.

Course 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.

OR&IE 480 Information Technology

Fall. 4 credits. Pre- or corequisites: COM S/ENGRD 211, plus either OR&IE 310 or OR&IE 350.

This is a project course that encompasses various aspects of information technology related to operations research and industrial engineering. Topics include the design of databases and information systems, the World Wide Web, the economics and industrial organization of IT goods and services, electronic markets, and agent based interactions.

OR&IE 481 Delivering OR Solutions with Information Technology

Spring. 2 credits. Prerequisites: OR&IE 480. Enrollment limited. M. Eisner.

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.

[OR&IE 483 Applications of Operations Research and Game Theory to Information Technology

Spring. 3 credits. Prerequisites: OR&IE 321, OR&IE 361 or permission of instructor. Not offered 2003–2004.

This course 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.]

OR&IE 490 Teaching in OR&IE

Fall, spring. Varying credit. Prerequisite: permission of instructor.

This course involves working as a TA in an OR&IE course. The course instructor assigns credits (the guideline is 1 credit per 4 hours/week of work with a limit of 3 credits).

OR&IE 499 OR&IE Project

Fall, spring. Varying 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.

OR&IE 512 Applied Systems Engineering I (also CEE 504, COM S 504, ECE 512, M&AE 591)

Fall. 3 credits. Prerequisite: permission of instructor. R. Roundy.

For description, SYSEN 510.

OR&IE 513 Applied Systems Engineering II (also CEE 505, COM S 505, ECE 513, M&AE 592)

Spring. 3 credits. Prerequisite: Applied Systems Engineering I (CEE 504, COM S 504, ECE 512, M&AE 592, or OR&IE 512). P. Jackson.

For description, see SYSEN 520.

OR&IE 515 Design of Manufacturing Systems

Fall. 4 credits. Prerequisite: permission of instructor. Limited to graduate students in Engineering and the Business School.

For description, see OR&IE 416.

OR&IE 516 Case Studies

Fall. 1 credit. Limited to M.Eng. students in OR&IE. M. Eisner.

Students are presented with an unstructured problem that resembles a real-world situation. They work in project groups to formulate mathematical models, perform computer analyses of the data and models, and present oral and written reports.

OR&IE 518 Supply Chain Management

Spring. 3 credits. Prerequisites: one of the following: OR&IE 310, OR&IE 416, OR&IE 525, or OR&IE 562. J. Muckstadt, H. Topaloglu.

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.

OR&IE 520 Operations Research I: Optimization I

For description, see OR&IE 320.

OR&IE 521 Optimization II

For description, see OR&IE 321.

OR&IE 522 Operations Research I: Topics in Linear Optimization

Fall. 1 credit. Pre- or corequisite: OR&IE 520. Students who have already taken OR&IE 321 or 521 should not enroll. Limited to M.Eng. students in OR&IE.

An extension of OR&IE 520 that deals with applications and methodologies of dynamic programming, integer programming, and large-scale linear programming.

OR&IE 523 Operations Research II: Introduction to Stochastic Processes I

For description, see OR&IE 361.

[OR&IE 524 Design of Manufacturing Systems II

Spring; weeks 8–14. 2 credits. Prerequisites: OR&IE 562, OR&IE 416; or by permission of instructor. Not offered 2003–2004.

This project course focuses on the design and analysis of a global corporation's operations. Working in teams, students examine issues pertaining to a prototype company on the following topics: information system design, marketing, strategy, location of facilities, organization design, manufacturing capacity, planning logistics, production planning, scheduling, inventory control, and financial analysis. Meetings between project teams and faculty are substituted for some lectures or laboratories. Analytical methods appropriate for conducting analysis are discussed in lectures.]

OR&IE 525 Production Planning and Scheduling Theory and Practice

Spring. 4 credits. Corequisite: OR&IE 320, OR&IE 360. A. Sapra.

Topics covered 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.

OR&IE 528–529 Selected Topics in Applied Operations Research

Fall, spring. Varying credit. Prerequisite: permission of instructor.

Current topics dealing with applications of operations research.

OR&IE 551 Economic Analysis of Engineering Systems

Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.

Lectures concurrent with OR&IE 451. For description see OR&IE 451.

OR&IE 560 Engineering Probability and Statistics II

For description, see OR&IE 360.

[OR&IE 561 Queuing Systems: Theory and Applications

Fall. 3 credits. Prerequisite: OR&IE 361 or permission of instructor. Not offered 2003–2004.

Course 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.]

OR&IE 562 Inventory Management
Fall. 3 credits. Prerequisite: OR&IE 321, 361, or permission of instructor. A. Sapra.
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 of this course 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.

OR&IE 563 Applied Time-Series Analysis
Fall. 3 credits. Prerequisites: OR&IE 361 and ENGRD 270 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.

[OR&IE 564 Introductory Engineering Stochastic Processes II
Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Lectures concurrent with OR&IE 462.
For description, see OR&IE 462.]

OR&IE 565 Applied Financial Engineering
Spring. 4 credits. Limited to M.Eng. students. P. Protter.
This course has two components: a sequence of lectures and a project. The course is co-listed with the Johnson School. The lectures are given by the faculty for the course and by invited speakers from the financial industry. The project satisfies the M.Eng. project requirement.

OR&IE 566 Extreme Value Analysis with Applications to Finance and Data Communications
Spring. 3 credits. S. Resnick.
For description, see OR&IE 464.

OR&IE 567 Credit Risk: Modeling, Valuation, and Management
Spring. 4 credits. Prerequisite: OR&IE 361. K. Giesecke.
For description, see OR&IE 467.

[OR&IE 569 Financial Engineering with Stochastic Calculus II
Spring. 4 credits. Prerequisite: OR&IE 468. Not offered 2003–2004.
For description, see OR&IE 469.]

[OR&IE 575 Experimental Design
Spring; weeks 8–14 (alternates with 576). 2 credits. Prerequisite: OR&IE 476. Not offered 2003–2004.
Course 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.]

OR&IE 576 Regression
Spring; weeks 8–14 (alternates with 575). 2 credits. Prerequisite: OR&IE 476. J. Booth.
Course 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.

OR&IE 577 Quality Control
Fall. 3 credits. Prerequisite: ENGRD 270. B. Turnbull.
Course 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.

OR&IE 580 Simulation Modeling and Analysis
Fall. 4 credits. Prerequisite: OR&IE 360 (may be taken concurrently) and computing experience, or permission of instructor. S. Henderson.
Introduction to Monte Carlo and discrete-event simulation. Emphasis on tools and techniques needed in practice. Random variate generation, input and output analysis, modeling using a discrete-event simulation package.

OR&IE 597 Systems Engineering Project
Fall; R grade only; spring, 8 credits. For M.Eng. students.
For M. Eng. Students enrolled in the Systems Engineering Option. A 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.

OR&IE 598 Master of Engineering Manufacturing Project
Fall. R grade only; spring, 5 credits. For M.Eng. students.
Project course for M.Eng. students enrolled in the Manufacturing Option coordinated by the Center for Manufacturing Enterprise.

OR&IE 599 Project
Fall. R grade only; spring, 5 credits. For M.Eng. students.
Identification, analysis, design, and evaluation of feasible solutions to some applied problem in the OR&IE field. A formal report and oral defense of the approach and solution are required.

OR&IE 625 Scheduling Theory
Spring. 3 credits. D. Shmoys.
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.

OR&IE 626 Advanced Production and Inventory Planning
Fall, spring. 4 credits. J. Muckstadt, fall; H. Topaloglu, spring.
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.

OR&IE 630 Mathematical Programming I
Fall. 4 credits. Prerequisites: advanced calculus and elementary linear algebra. R. Bland.
A 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.

OR&IE 631 Mathematical Programming II
Spring. 4 credits. Prerequisite: OR&IE 630. L. Trotter.
A continuation of OR&IE 630. Introduction to nonlinear programming, interior-point methods for linear programming, complexity theory, and integer programming. Includes some discussion of dynamic programming and elementary polyhedral theory.

[OR&IE 632 Nonlinear Programming
Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 2003–2004.
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).]

[OR&IE 633 Graph Theory and Network Flows
Spring. 3 credits. Prerequisite: permission of instructor. Not offered 2003–2004.
Topics covered 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.]

[OR&IE 634 Combinatorial Optimization
Spring. 3 credits. Not offered 2003–2004.
Topics in combinatorics, graphs, and networks, including matching, matroids, polyhedral combinatorics, and optimization algorithms.]

OR&IE 635 Interior-Point Methods for Mathematical Programming
Fall. 3 credits. Prerequisites: MATH 411 and OR&IE 630, or permission of instructor. M. Todd.
Interior-point methods for linear, quadratic, and semidefinite programming and, more generally, for convex programming. Discussion of 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. Emphasis on recent mathematical theory and the most modern viewpoints.

[OR&IE 636 Integer Programming
Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 2003–2004.
Topics covered 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.]

[OR&IE 637 Semidefinite Programming
Spring; weeks 8–14. 2 credits. Pre- or corequisite: OR&IE 635. Not offered 2003–2004.
Course 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.]

[OR&IE 639 Polyhedral Convexity
Spring. 3 credits. Prerequisite: basic knowledge of linear algebra. Not offered 2003–2004.
A comprehensive introduction to the geometry and combinatorics of polyhedral convex sets. Also, linear inequalities, supporting and separating hyperplanes; polarity; convex hulls, facets, and vertices; face lattices; convex cones and polytopes; minkowski sums; gale transforms; simplicial and polyhedral subdivision; and applications to linear programming, combinatorial optimization, and computational geometry.]

OR&IE 650 Applied Stochastic Processes
Fall. 4 credits. Prerequisite: a 1-semester calculus-based probability course. U. Prabhu.
An 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.

OR&IE 651 Probability
Spring. 4 credits. Prerequisite: real analysis at the level of MATH 413 and a previous 1-semester course in calculus-based probability. P. Protter.
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.

[OR&IE 662 Advanced Stochastic Processes
Fall. 3 credits. Prerequisite: OR&IE 651 or equivalent. Not offered 2003–2004.
Course 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.]

OR&IE 670 Statistical Principles
Fall. 4 credits. Corequisite: OR&IE 650 or equivalent. B. Turnbull.
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.

OR&IE 671 Intermediate Applied Statistics
Fall. 3 credits. Prerequisite: OR&IE 670 or equivalent. J. Booth.
Course 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.

[OR&IE 674 Statistical Learning Theory for Data Mining
Spring. 3 credits. Prerequisites: Probability at the level of OR&IE 651, and statistical at the level of OR&IE 670. Not offered 2003–2004.
This course will provide a thorough grounding in probabilistic and computational methods for statistical data mining. We intend to cover 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.]

[OR&IE 677 Sequential Methods in Statistics
Spring. 3 credits. S-U grades only. Not offered 2003–2004.
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. Topics in this course include 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.]

OR&IE 678 Bayesian Statistics and Data Analysis
Spring. 3 credits. Prerequisites: OR&IE 670 and some knowledge of measure theoretic probability, e.g., co-registration in OR&IE 650. D. Ruppert.
Priors, posteriors, Bayes estimators, Bayes factors, credible regions, hierarchical models, computational methods (especially MCMC), empirical Bayes methods, Bayesian robustness. The course will include data analysis and MCMC computation in WinBUGS and possibly other languages such as MATLAB.

OR&IE 680 Simulation
Spring. 4 credits. Prerequisite: computing experience and OR&IE 650 or equivalent, or permission of instructor. S. Henderson.
Introduction to Monte Carlo and discrete-event simulation. Emphasis on underlying theory. Random variate generation, input and output analysis, variance reduction, selection of current research topics.

OR&IE 728–729 Selected Topics in Applied Operations Research
Fall, spring. Credit TBA.
Current research topics dealing with applications of operations research.

OR&IE 738–739 Selected Topics in Mathematical Programming
Fall, spring. Credit TBA.
Current research topics in mathematical programming.

OR&IE 768–769 Selected Topics in Applied Probability
Fall, spring. Credit TBA.
Topics are chosen from current literature and research areas of the staff.

OR&IE 778–779 Selected Topics in Applied Statistics
Fall, spring. Credit TBA.
Topics chosen from current literature and research of the staff.

OR&IE 790 Special Investigations
Fall, spring. Credit TBA.
For individuals or small groups. Study of special topics or problems.

OR&IE 799 Thesis Research
Fall, spring. Credit TBA.
For individuals doing thesis research for master's or doctoral degrees.

OR&IE 891 Operations Research Graduate Colloquium
Fall, spring. 1 credit. Staff.
A weekly 1–1/2 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.

OR&IE 893–894 Enterprise Engineering Colloquium (also M&AE 594)
893, fall; 894, spring. 1 credit (usually S-U) each term.
A 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.

SYSTEMS ENGINEERING

SYSEN 510 Applied Systems Engineering I (also CEE 504, COM S 504, ECE 512, M&AE 591, OR&IE 512)
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. Staff.
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 510. Students in Continuing Education enroll in SYSEN 511. Students taking option in Systems Engineering enroll in M&AE 491, CEE 504, COM S 504, ECE 512, or OR&IE 512. Lectures are identical for all versions.

SYSEN 511 Applied Systems Engineering I Fundamentals
Fall. 3 credits. Prerequisites: senior or graduate standing in an engineering field; concurrent or recent (past two years) enrollment in a group-based project with a strong system design component that is approved by a course instructor. Staff.

For description see SYSEN 510. Students majoring in Systems Engineering enroll in SYSEN 510. Students in Continuing Education enroll in SYSEN 511. Lectures are identical for all versions.

SYSEN 520 Applied Systems Engineering II (M&AE 592, CEE 505, COM S 505, ECE 513, or OR&IE 513)
Spring. 3 credits. Prerequisites: Applied System Engineering I (M&AE 591, CEE 504, COM S 505, ECE 512, or OR&IE 512) or permission of instructor. Staff.
This is an advanced course in the application of the systems engineering process to the design and operation of complex systems. Topics introduced in Applied Systems Engineering I will be covered in greater depth. Topics include techniques for design, simulation, optimization, and control of complex systems. Case studies and system simulations in diverse areas will provide context for the application of these techniques. Students majoring in Systems Engineering enroll in SYSEN 520. Students taking Option in Systems Engineering enroll in M&AE 592, CEE 505, CS 505, EE 513, or OR&IE 513. Students in Continuing Education enroll in SYSEN 521. Lectures are identical for all versions.

SYSEN 521 Applied Systems Engineering II Fundamentals
Spring. 3 credits. Prerequisites: Applied System Engineering I Fundamentals or permission of instructor. Staff.
For description see SYSEN 520. Students in Continuing Education enroll in SYSEN 521. Lectures are identical for all versions.

SYSEN 570 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 571 Practicum in Systems Engineering
On demand. 3 credits. Staff.
Supervised study by individuals or small groups of one or more specialized topics not covered in regular courses.

SYSEN 590 Systems Engineering Design Project
Fall. 6–8 credits. Prerequisites: 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.

THEORETICAL AND APPLIED MECHANICS

Basics in Engineering Mathematics and Mechanics

T&AM 118 Design Integration: A Portable CD Player (also ENGRI 118 and MS&E 118)
Spring. 3 credits.
This is a course in the Introduction to Engineering series. For description, see ENGRI 118.

T&AM 202 Mechanics of Solids (also ENGRD 202)
Fall, spring. 4 credits Prerequisite: PHYS 112, coregistration in MATH 192 or permission of instructor.
For description, see ENGRD 202.

T&AM 203 Dynamics (also ENGRD 203)
Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in MATH 293, or permission of instructor.
For description, see ENGRD 203.

Engineering Mathematics

T&AM 190 Calculus for Engineers (also MATH 190)
Fall. 4 credits. Prerequisite: 3 years of high school mathematics, including trigonometry and logarithms.
For description, see MATH 190.

T&AM 191 Calculus for Engineers (also MATH 191)
Fall. 4 credits. Prerequisite: 3 years of high school mathematics, including trigonometry.
For description, see MATH 191.

T&AM 192 Calculus for Engineers (also MATH 192)
Fall, spring, or summer. 4 credits. Prerequisite: MATH/T&AM 191.
For description, see MATH 192.

T&AM 293 Engineering Mathematics (also MATH 293)
Fall, spring. 4 credits. Prerequisite: MATH/T&AM 192 plus a knowledge of computer programming equivalent to that taught in COM S 100.
For description, see MATH 293.

T&AM 294 Engineering Mathematics (also MATH 294)
Fall, spring. 4 credits. Prerequisite: MATH/T&AM 293.
For description, see MATH 294.

T&AM 310 Advanced Engineering Analysis I
Fall, spring. 3 credits. Prerequisite: MATH/T&AM 294 or equivalent.
Course 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.

T&AM 311/511 Advanced Engineering Analysis II
Spring. 3 credits. Prerequisite: MATH/T&AM 294 or equivalent (T&AM 311 can be taken without T&AM 310).
Mathematical modeling of physical and biological systems. Examples range from molecular diffusion, bacteria swimmers, chemotaxis, and physiological flows, to bird flight. The mathematics necessary to understand these phenomena is discussed in depth. They include probability theory, PDEs, stability analysis, complex variable analysis, and numerical analysis. Students from all fields are encouraged to take the course.

T&AM 610 Methods of Applied Mathematics I
Fall. 3 credits. Intended for beginning graduate students in engineering and science. An intensive course, requiring more time than is normally available to undergraduates (see T&AM 310–311) but open to exceptional undergraduates with permission of instructor.
Emphasis is on applications. Course covers: linear algebra, calculus of several variables, vector analysis, series, ordinary differential equations, and complex variables.

T&AM 611 Methods of Applied Mathematics II
Spring. 3 credits. Prerequisite: T&AM 610 or equivalent.
Emphasis is on applications. Course covers: partial differential equations, transform techniques, tensor analysis, calculus of variations.

T&AM 612 Methods of Applied Mathematics III
Spring. 3 credits. Prerequisite: T&AM 610 and 611 or equivalent.
Course topics include: integral transform, methods, Wiener-Hopf technique, solutions of integral equations and partial differential equations. Problems are drawn from electromagnetics, elasticity, fluid mechanics, heat transfer, and acoustics.

T&AM 613 Methods of Applied Mathematics IV
Spring. 3 credits. Prerequisite: T&AM 610 and 611 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.

[T&AM 614 Methods of Applied Math V
Spring. 3 credits. Prerequisites: T&AM 610 plus T&AM 611 or equivalent. Not offered 2003–2004.]

T&AM 617 Advanced Mathematical Modeling
Spring. 3 credits. Offered alternate years.

T&AM 718 Topics in Bifurcation Theory
Spring. 3 credits. Offered every third year.
Provides a basic, rigorous introduction to certain aspects of nonlinear analysis, with an emphasis on techniques based on differential calculus. Applications to nonlinear elasticity and nonlinear oscillations of mechanical systems (including Liapunov Center Theorem, Hopf Bifurcation, and Hamiltonian-Hopf bifurcation) will be presented throughout. The course is intended for students in the physical and mathematical sciences. The minimal prerequisites are linear algebra, advanced calculus, differential equations, and eigenvalue problems. Exposure to nonlinear problems of engineering science or mathematical physics and some background in basic functional analysis is helpful but not required.

Continuum Mechanics

T&AM 455 Introduction to Composite Materials (also CEE 475, M&AE 455 and MS&E 555)
Spring. 4 credits.
Course 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 composities. There is a group component design and manufacturing paper required, and a group laboratory on laminated component fabrication.

T&AM 591 Master of Engineering Design Project I
Fall. 3–10 credits.
M. Eng. (Mechanics) project related to the Master of Engineering Mechanics.

T&AM 592 Master of Engineering Design Project I
Spring. 3–10 credits.
M. Eng. (Mechanics) project related to the Master of Engineering Mechanics.

T&AM 655 Composite Materials (also M&AE 655 and MS&E 655)
Spring. 4 credits.
Taught jointly with T&AM 455 using same lecture material, but also includes more advanced material and homework through additional lectures. Additional material includes shear-lag models of stress transfer around arrays of fiber breaks, including viscoelastic effects, statistical theories of composite strength and failure; stress distributions around holes and cuts in composite laminates; and compressive strength of composites. Laboratory on effects of holes and notches in composites.

T&AM 663 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.

T&AM 664 Solid Mechanics II
Spring. 4 credits. Prerequisites: MATH 610 and T&AM 663 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.

T&AM 666 Finite Element Analysis (also M&AE 680 and CEE 772)
Spring. 3 credits. Prerequisites: T&AM 663 or equivalent.
For description, see M&AE 680.

T&AM 751 Continuum Mechanics and Thermodynamics
Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 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.

T&AM 752 Nonlinear Elasticity
Spring. 3 credits. Prerequisites: T&AM 610, 611, and 751 or equivalents. Offered alternate years.
Review of governing equations. Topics include linearization and stability; constitutive inequalities; exact solution of special problems; nonlinear string and rod theories; phase transformations and crystal defects.

T&AM 753 Fracture
Fall. 3 credits. Prerequisites: T&AM 610 or 611; and 663 and 664 or equivalents. Offered alternate years.
Course covers fundamentals of linear elastic fracture mechanics: K, small-scale yielding, solutions of elastic crack problems, energy concepts, J-integral. Also covers nonlinear, rate-independent, small-deformation, fracture mechanics: plastic fracture, J-integral, small-scale yielding, fields for stationary and growing cracks; failure mechanisms of polymers, ceramics, composites, and metals: void growth, load transfer between fibers, crazing; fracture testing; fatigue fracture; computation of stress intensity factors; and plate theory and fracture.

[T&AM 757 Inelasticity
Spring. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years. Not offered 2003–2004.
Course covers plasticity: dislocation slip systems; early experimental observations; general principles; limit analysis; and solution of boundary-value problems, plastic waves, one- and three-dimensional. Also covers viscoelasticity: general principles, solution of boundary-value problems.]

[T&AM 759 Boundary Element Methods
Fall. 4 credits. Prerequisites: T&AM 610 and 611; and 633 and 644 or equivalents. Offered alternate years. Not offered 2003–2004.
Introduction to boundary element methods. Solutions for potential theory, linear elasticity, diffusion, material, and/or geometric nonlinearities. Modern developments: hypersingular integrals, the boundary contour methods, sensitivity analysis.]

Dynamics and Space Mechanics

T&AM 570 Intermediate Dynamics
Fall. 3 credits.
Course 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.

T&AM 578 Nonlinear Dynamics and Chaos
Fall. 3 credits. Prerequisite: MATH/T&AM 293 or equivalent.
Introduction to nonlinear dynamics, with applications to physics, engineering, biology, and chemistry. Emphasizes analytical methods, concrete examples, and geometric thinking. Topics: one-dimensional systems; bifurcations; phase plane; nonlinear oscillators; and Lorenz equations, chaos, strange attractors, fractals, iterated mappings, period doubling, renormalization.

T&AM 671 Hamiltonian Dynamics
Spring. 3 credits. Prerequisite: T&AM 570 or equivalent. Offered alternate years.
Course topics include review of Lagrangian mechanics, Kane's equations; Hamilton's principle, the principle of least action, and related topics from the calculus of variations; Hamilton's canonical equations; approximate methods for two-degrees-of-freedom systems (Lie transforms); canonical transformations and Hamilton-Jacobi theory; KAM theory; and Melnikov's method.

T&AM 672 Celestial Mechanics (also ASTRO 579)
Spring. 3 credits. Offered alternate years.
Course topics include description of orbits; 2-body, 3-body, and n-body problems; 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.

T&AM 673 Mechanics of the Solar System (also ASTRO 571)
Spring. 3 credits. Prerequisite: an advanced undergraduate course in dynamics. Offered alternate years; offered 2003–2004.
Course topics include gravitational potentials, planetary gravity fields; free and forced rotations; Chandler wobble, polar wander, and damping of nutation; equilibrium tidal theory, tidal heating; orbital evolution of natural satellites, resonances, spin-orbit coupling, Cassini states; long-term variations in planetary orbits; dust dynamics; dynamics of ring systems; and physics of interiors, seismic waves, free oscillations. Illustrative examples are drawn from contemporary research.

T&AM 675 Nonlinear Vibrations
Spring. 3 credits. Prerequisite: T&AM 578 or equivalent. Offered alternate years.
Quantitative analysis of weakly nonlinear systems in free and forced vibrations, perturbation methods, averaging method. Applications to problems in mechanics, physics, and biology. Additional topics may include Hopf bifurcation, Invariant manifolds, coupled oscillators, vibrations in continuous media, normal forms, and exploitation of symmetry.

[T&AM 678 Complex Systems
Spring. 3 credits. Prerequisites: T&AM 578 or equivalent. Offered alternate years; Not offered 2003–2004.
Complex systems in physics, biology, engineering, economics, and the Internet. Topics: power laws, percolation, phase transitions, scaling, and renormalization. Self-organized criticality; neural, cardiac, genetic, power grid; and financial networks. Stochastic spatial models. Evolution on rugged landscapes.]

T&AM 776 Applied Dynamical Systems (also MATH 717)
For description, see MATH 717.

Special Courses, Projects, and Thesis Research

T&AM 491–492 Project in Engineering Science

Fall, 491; spring, 492. 1–4 credits, as arranged.

Projects for undergraduates under the guidance of a faculty member.

T&AM 796–800 Topics in Theoretical and Applied Mechanics

Fall, spring. 1–3 credits, as arranged.

Special lectures or seminars on subjects of current interest. Topics are announced when the course is offered.

T&AM 890 Master's Degree Research in Theoretical and Applied Mechanics

Fall, spring. 1–15 credits, as arranged. S-U grades optional.

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.

T&AM 990 Doctoral Research in Theoretical and Applied Mechanics

Fall, spring. 1–15 credits, as arranged. S-U grades optional.

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 at Berkeley. Prof., Civil and Environmental Engineering

Ahner, Beth A., Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Biological and Environmental Engineering

Albright, Louis D., Ph.D., Cornell U. Prof., Biological and Environmental Engineering

Allmendinger, Richard, Ph.D., Stanford U. Prof., Earth and Atmospheric Sciences

Aneshansley, Daniel J., Ph.D., Cornell U. 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 Assistant 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. Assoc. Prof., Chemical and Biomolecular Engineering

Arms, William, Ph.D., U. of Sussex. Prof., Computer Science

Ast, Dieter G., Ph.D., Cornell U. Prof., Materials Science and Engineering

Athreya, Krishna B., Ph.D., Stanford U. Prof., Operations Research and Industrial Engineering

Avedisian, C. Thomas, Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering

Baeumner, Antje J., Ph.D., Universitat Stuttgart. Asst. Prof., Biological and Environmental Engineering

Bailey, Graeme, Ph.D., U. of Birmingham. Prof., Computer Science

Baker, Shefford P., Ph.D., Stanford U. Asst. Prof., Materials Science and Engineering

Bala, Kavita, Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Computer Science

Ballantyne, Joseph M., Ph.D., Massachusetts Inst. of Technology. Prof., Electrical and Computer Engineering

Barazangi, Muawia, Ph.D., Columbia U. Prof., Earth and Atmospheric Sciences

Bartel, Donald L., Ph.D., U. of Iowa. Prof., Mechanical and Aerospace Engineering

Bartsch, James A., Ph.D., Purdue U. Assoc. Prof., Biological and Environmental Engineering

Berger, Toby, Ph.D., Harvard U. Irwin and Joan Jacobs Professor of Engineering, Electrical and Computer Engineering

Berndt, Antje, Ph.D., Stanford U. Asst. Prof., Operations Research and Industrial Engineering

Bird, John M., Ph.D., Rensselaer Polytechnic Inst. Prof., Earth and Atmospheric Sciences

Birman, Kenneth P., Ph.D., U. of California at Berkeley. Prof., Computer Science

Bisogni, James J., Ph.D., Cornell U. Assoc. Prof., Civil and Environmental Engineering

Blakely, John M., Ph.D., Glasgow U. (Scotland). Herbert Fisk Johnson Professor of Engineering, Materials Science and Engineering

Bland, Robert G., Ph.D., Cornell U. Prof., Operations Research and Industrial Engineering

Bojanczyk, Adam W., Ph.D., U. of Warsaw (Poland). Assoc. Prof., Electrical and Computer Engineering

Bonassar, Lawrence J., Ph.D., Massachusetts Inst. of Technology. Assoc. Prof., Mechanical and Aerospace Engineering

Booker, John F., Ph.D., Cornell U. Prof. Emeritus, Mechanical and Aerospace Engineering

Brock, Joel D., Ph.D., Massachusetts Inst. of Technology. Director and Prof., Applied and Engineering Physics

Brown, Larry D., Ph.D., Cornell U. Prof., Earth and Atmospheric Sciences

Brutsaert, Wilfried H., Ph.D., U. of California at Davis. William L. Lewis Prof. of Engineering, Civil and Environmental Engineering

Buhrman, Robert A., Ph.D., Cornell U. John Edson Sweet Professor of Engineering, Applied and Engineering Physics

Burns, Joseph A., Ph.D., Cornell U. Irving Porter Church Professor of Engineering, Astronomy and Theoretical and Applied Mechanics

Burtscher, Martin, Ph.D., U. of Colorado at Boulder. Asst. Prof., Electrical and Computer Engineering

Cady, K. Bingham, Ph.D., Massachusetts Inst. of Technology. Prof., Theoretical and Applied Mechanics; Nuclear Science and Engineering

Callister, John R., Ph.D., Cornell U. Kinzelberg Director of Entrepreneurship in Engineering

Campbell, Mark E., Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Mechanical and Aerospace Egineering

Cardie, Claire T., Ph.D. U. of Massachusetts at Amherst. Assoc. Prof., Computer Science

Caruana, Richard, Ph.D., Carnegie Mellon U. Asst. Prof., Computer Science

Castillo-Chavez, Carlos, Ph.D., U. of Wisconsin at Madison. Prof., Theoretical and Applied Mechanics, Biometry, Applied Mathematics, Ecology and Evolutionary Biology, Statistics, Epidemiology, Latin American Studies

Cathles, Lawrence M. III, Ph.D., Princeton U. Prof., Earth and Atmospheric Sciences

Caughey, David A., Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering

Chiang, Hsiao-Dong, Ph.D., U. of California at Berkeley. Prof., Electrical and Computer Engineering

Cisne, John L., Ph.D., U. of Chicago. Prof., Earth and Atmospheric Sciences

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